NextGen Improved Approaches & Low Visibility Operations (IALowVis)

Ground Based Augmentation System (GBAS)

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Update GBAS Concept of Operations (GAST-D)

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Updated GBAS Concept of Operations (GAST-D)

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Ground Based Augmentation System

(GBAS)

Concept of Operations
(GAST-D)

DOCUMENT CHANGE RECORD

Version	Date	Changes	Remarks

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1 INTRODUCTION/SCOPE

The International Civil Aviation Organization (ICAO) and the civil aviation community have recognized that the primary means of radio navigation for the 21st century will be based on a Global Navigation Satellite System (GNSS). In September 1991, the United States formally offered the Global Positioning System (GPS) as an element of a worldwide GNSS.

The 2014 Federal Radio Navigation Plan policy states the "Aeronautical Transition Policy is to Transition to Satellite-Based Radionavigation". FRD 5.7.1 Transition to Satellite-based PNT:

> *FAA is transitioning to providing SATNAV services based primarily on GPS augmented by aircraft-based augmentation systems (ABAS), such as Receiver Autonomous Integrity Monitoring (RAIM); SBAS, such as WAAS; and GBAS. As a result of this transition, the need for ground-based navigation services will diminish, and the number of federally provided ground-based facilities will be reduced accordingly, but with sufficient time for users to equip with SATNAV avionics.*
>
> *The pace and extent of the transition to SATNAV will depend upon a number of factors, including:*
>
> - *NAS performance;*
> - *achievement of GPS and GPS augmentation systems program milestones;*
> - *and user acceptance.*

GBAS is intended to provide CAT I/II/III precision approach and landing capability, and may provide Differentially Corrected Positioning Service (DCPS) suitable for Area Navigation (RNAV) and Required Navigation Performance (RNP) based procedures.

GBAS may in the future support terminal area operations with extended service volume, extended service volume is defined as GBAS service that supports operations beyond 23 nm from the GBAS reference point . The versatility of the airborne receiver and DCPS may support terminal RNP-RNAV procedures, including Departure Procedures (DPs), Standard Terminal Arrival Routes (STARs), and curved and segmented approach paths.

1.1 Background

GBAS is part of the NextGen Separation Management Portfolio, which conducts pre-implementation activities to reduce risk, and implementation activities supporting the safe and efficient separation of aircraft and other vehicles in the National Airspace System (NAS). The Separation Management Portfolio identifies improvements to runway access through the use of improved technology, updated standards, safety analysis, and modifications to air traffic monitoring tools and operating procedures that will enable more arrival and departure operations. GBAS is identified in the Enterprise Architecture and the Navigation Roadmap as the future navigation solution for Category (CAT) II and III precision approach and autoland operations. High integrity navigation services will be provided with a minimum investment in ground facilities compared to existing ILS technology. GBAS is a single facility that can serve an entire airport and is capable of providing precision approach capabilities to all runway ends.

GBAS is a component of the FAA plan to transition from a ground-based navigation and landing system to a satellite-based navigation system. The strategy to achieve this capability is to initially develop and approve a single frequency GBAS to provide CAT I service and improve this architecture to provide CAT II/III service. The FAA decided against deployment of CAT I GBAS based on projected cost benefit analysis as well as duplication of similar capabilities (LPV 200 = CAT I like) provided by the Wide Area Augmentation System. GBAS CAT I was developed in cooperation with industry and international service providers and granted FAA approval in September 2009. GBAS CAT I systems may be implemented as non-Federal systems by airport authorities based on their customer requests.

FAA Standards and Technical Standing Order (TSO) for GBAS CAT I avionics are approved and GBAS is available in commercial Boeing and AIRBUS aircraft. Approved avionics are available and many commercial carriers began equipage and crew training, and on a regular basis use GBAS for precision approach and landing where available. GBAS avionics equipage is available either as an option for or standard feature on different aircraft types.

A GBAS CAT I design, the Honeywell SLS-4000 was approved by the FAA in September 2009 as a Non-Fed system for use within the NAS. The FAA signed a cooperative agreement with the Port Authority of New York and New Jersey (PANYNJ) in support of their installation of GBAS at Newark, New Jersey. The Newark GBAS is fully operational as of September 28, 2012. An additional SLS-4000 was installed at George Bush Intercontinental Airport (IAH) as a Non-Fed system by the Houston Airport System (HAS) in 2011 and has been operational since April 22, 2013. Both EWR and IAH are used on a regular basis by GBAS-equipped aircraft from national and international airlines (United Airlines, Delta Airlines, Lufthansa, Emirates, Cathay Pacific, and British Airlines).

An increasing number of users (airlines) have already introduced GBAS-capable Boeing and Airbus aircraft into their fleet operations. All new generation Boeing and Airbus aircraft will be GBAS capable with either standard avionics capability or GLS as an option. Boeing reported (as of April 2016) that 47% of all deliveries are with GLS activated-- over 60 airlines and over 1500 airplanes. Airbus reported similar statistics (as of April 2016) with 43 airlines with activated GLS.

The CAT II/III development for GBAS builds on the original CAT I GBAS developments. This is accomplished by introducing the concept of service types. Service Types are matched sets of airborne and ground performance and functional requirements. GBAS approach services are further differentiated into multiple types referred to as GBAS Approach Service Types (GAST).
A GAST is defined as the matched set of airborne and ground performance and functional requirements that are intended to be used in concert in order to provide approach guidance with quantifiable performance. Four types of approach service; GAST A, GAST B, GAST C and GAST D are currently proposed.

The GBAS GAST-D concept was developed by ICAO NSP (Navigation System Panel) to allow GBAS to support CAT II/III approach and landing operations using GPS L1. The only GBAS CAT II/III ICAO standard is the GAST-D Baseline Document Standard and its companion document, the GBAS GAST-D Technical Concept Paper. This standard is addressing the case of a GBAS System based on GPS L1 constellation only and intends to support CAT III operations, however it focuses mainly on the technical requirements and moreover on the ground station and constellation ones.

ICAO GBAS standards for GAST-D, a service type equivalent to ILS CAT III, were baselined within the ICAO SARPS in 2011. The ICAO working group, in which the FAA participates, has the goal to complete the GBAS standards validation work by 2016.

1.2 Problem Statement

The Next Generation Air Transportation (NextGen) technologies and procedures, along with infrastructure construction and improvements, will provide the tools for airports to accommodate future growth. The greatest benefits will come from integrated airport planning and terminal airspace redesign projects that deliver new airport infrastructure served by NextGen Performance Based Navigation (PBN) capabilities. Improved safety and access to runways are an important goal of NextGen. Satellite-based technologies are improving access to runways at both large and small airports.

Current navigational aids, particularly Instrument Landing System (ILS), are unable to support advanced procedures required to increase airport arrival and departure throughput and enable on-airport surface navigation. ILS has technical limitations which prevent it from achieving many of the capacity and efficiency benefits of a satellite based navigation system. The ILS system is installed in the runway area and is subject to multi-path effects which place restrictions on building development and also on aircraft movements in the airport. In low visibility conditions the flight crew is required to use on-board automation (i.e. autoland) for approach and landing that are highly dependable on the ILS signal. Due to the technical nature of the ILS signal the ILS protection areas become larger in low visibility and aircraft entering the runway areas are required to hold on the CAT III holding points as opposed to CAT I holding points, which are closer to the runway and used in good visibility. This results in restricted ground movements and greater final approach spacing margins between aircraft in order to accommodate the subsequently longer runway occupancy times (ROT).

In addition, a large percentage of ILSs in the National Airspace System (NAS) inventory are approaching the end of their useful life cycle (approximately 20 years). In order to continue as the primary approach and landing aid in the NAS, a majority of ILS will require either a service life extension or replacement in the 2018 to 2025 time frame. However, a service life extension will not result in improved ILS performance. The reason for the implementation of GBAS is to provide additional capabilities and benefits not found using ILS, thereby offering new opportunities in terms of operation to ATM stakeholders.

Concept Level	Problem Statement
1	Forecast traffic demand will exceed existing capacity of the NAS as it is currently configured, making approach efficiency more significant than today.
2	Published approach procedures that are based upon ground-based NAVAIDs diminish efficiency and flexibility of user flight profiles, disruption of which will impact capacity, efficiency, and the economics of air transportation.
3	Arrivals and departures at high-density airports, particularly during peak periods and inclement weather, are increasingly dependent on area navigation and smooth and early transition to the final precision approach procedure
4	***No satellite navigation CAT IIIa/b capability:*** the *2014 Federal Radio Navigation Plan* policy states that the FAA is transition to satellite-based radio navigation. In addition, the NextGen Mid-term concept of operations outlines the evolution towards a performance-based NAS by using a satellite based navigation system and onboard technologies to allow for more precise positioning information. These improvements allow greater flexibility to navigate airspace safely and efficiently. ***IlS signal quality and technical limitations:*** (1) ILS signal distortions outside the FAF can cause the aircraft to wander around the centreline. However, it might still appear to the pilot that the aircraft remains on the approach path and within the NOZ. This event typically occurs beyond FAF (10 nm) of the approach. (2) ILS performance can be dependent on the distance from the threshold; very short final segments maybe infeasible. (3) ILSs are susceptible to signal distortions from other aircraft and airport infrastructure and construction. (4) Finally, an ILS has one fixed glide slope and no capability for selectable thresholds. It does not provide the flexibility to program approach paths to whichever one is the most operationally feasible or the flexibility to have multiple procedures for one runway (different glide angles). ***Restrictions due to ILS critical areas:*** restrictions due to ILS critical areas can reduce ground movement delays. These areas pose operational restrictions and have an adverse effect on overall airport efficiency. ***No precision approach access where ILS siting constraints exist:*** There is a need for precision approach capability on certain runway ends where siting constraints have prevented ILS from being implemented. ***Capacity constraints due to wake turbulence/ CSPO:*** current ILSs have a fixed glide path angle which requires extended spacing due to wake turbulence. This places a constraint on airport capacity. The reduction in separation by mitigating

	wake turbulence and the capability for CSPO will allow for an increase in capacity. ***Higher decision heights with other satellite-based navigation (RNAV/RNP):*** current satellite-based navigation services do not provide the lowest decision heights possible. ***Limited availability of RNAV/RNP in terminal environment:*** RNAV/RNP equipment has limited availability due its dependence on RAIM to ensure the integrity of the aircraft positioning solution. An increase in RNAV/RNP availability will result in improved airport access and capacity.

Table 1: Problem Statement

1.3 Identification

The concept is derived from the NextGen Concept of Operations and flows to selected subset concepts relating to satellite-based navigation and precision approach operations. GBAS has been identified in the Enterprise Architecture, the Navigation Roadmap, and NextGen Implementation Plan 2015 as a future navigation solution for Improved Approaches and Low Visibility Operations for Category II and III precision approach and autoland operations.

GBAS relationship to other concepts:

Concept of Operations for the Next Generation Air Transportation System
(Level 1)

Performance Based Navigation
NAS Navigation Strategy 2016
(Level 2)

Operational Improvement
Ground-Based Augmentation System Precision Approaches
(OI 107107)
(Level 3)

GBAS Concept of Operations
(Level 4)

GBAS maps to several operational improvements (OIs) on the service roadmaps for NextGen.

- Ground-Based Augmentation System Precision Approaches (OI 107107)
- Improve Closely Spaced Parallel Runway Operations (OI 102141)
- Increase Capacity and Efficiency Using Area Navigation (RNAV) and Required Navigation Performance (RNP) (OI 108209)
- RNAV SIDs, STARs, and Approaches (OI 107103)
- Low Visibility/Ceiling Approach Operations (OI 107117)
- Low-Visibility/Ceiling Landing Operations (OI 107118)
- Low visibility/Ceiling Departures (107 116)

1.4 Concept Overview

1.4.1 Concept Level 1 – Far Term Concept of Operations (CONOPS)

The NAS Far-Term CONOPS document provides a high-level description of operations for NAS operations.

1.4.2 Concept Level 2 – PBN NAS Navigation Strategy - 2016

PBN NAS Navigation Strategy - 2016 provides a future NAS view building upon past PBN accomplishments. It also provides a view of the future implementation plans and resource requirements to meet goals necessary to fully transition to a PBN-centric NAS. GBAS is identified as the means to support precision approach operations and provide a resilient navigation infrastructure.

1.4.3 Concept Level 3 – OI 107107 – Ground-Based Augmentation System Precision Approaches

GBAS is part of the NextGen Separation Management Portfolio, which conducts pre-implementation activities to reduce risk, and implementation activities supporting the safe and efficient separation of aircraft and other vehicles in the National Airspace System (NAS). Risk reduction activities may include validation of concepts or technologies; demonstration and integration of operational capabilities; and an understanding of the role of the human through cognitive engineering experiments. Separation Management evaluates and matures concepts and capabilities that focus on the enhancement of separation assurance through the use of both ground based automation and aircraft technology enhancements. Separation Management will provide recommendations to improve the tools and procedures that air traffic controllers use to separate aircraft with different kinds of navigation equipment and wake performance capabilities. The Separation Management Portfolio identifies improvements to runway access through the use of improved technology, updated standards, safety analysis, and modifications to air traffic monitoring tools and operating procedures that will enable more arrival and departure operations.

1.4.4 Concept Level 4 – GBAS Concept of Operations

Satellite navigation is a primary enabler of RNAV/RNP resulting in fuel and time savings to the user. Approach and landing guidance, formerly provided by ground-based systems, is also available from satellite-based RNAV or RNP procedures, however RNP procedures supported by GPS and SBAS alone cannot meet CAT I, II, III criteria. Only GBAS Landing System (GLS) has been designed specifically to meet the highest levels of precision approach. RNAV/ RNP procedures or any other transition to a GBAS final approach have the advantage of GBAS accuracy, availability, integrity, and continuity necessary to safely support the lowest precision approach minima in all weather conditions.

GBAS provides GPS ranging source integrity monitoring, real-time corrections for GPS ranging signals, and ground system error bounds for users within the GBAS service volume. The GBAS consists of three separate segments; the Ground Facility, the Space Segment, and the Airborne Subsystem. GBAS uses a VHF Data Broadcast (VDB) in the band 108 to 117.975 MHz to communicate between the ground and airborne systems. The ground facility provides differential corrections, integrity parameters, and precision approach path point data referenced references to the airport coordinate system, defining the path in space to enable the precision approach operations broadcast via a Very High Frequency (VHF) Data Broadcast (VDB) to the Airborne Subsystem for processing. The Space Segment provides the GBAS ground facility and Airborne Subsystem with GPS ranging signals and orbital parameters. The Space Segment also provides the ground facility and Airborne Subsystem with optional Satellite-Based Augmentation System (SBAS) ranging signals and orbital parameters. "The Airborne Subsystem applies the ground facility corrections to the GPS ranging signals to obtain a corrected position with the required accuracy, integrity, continuity, and availability when within the operational service volume of the ground station. The corrected position is used within the GBAS avionics, along with path point data, to supply vertical and horizontal deviation signals (similar to ILS) to drive appropriate aircraft systems supporting terminal area and precision approach operations.

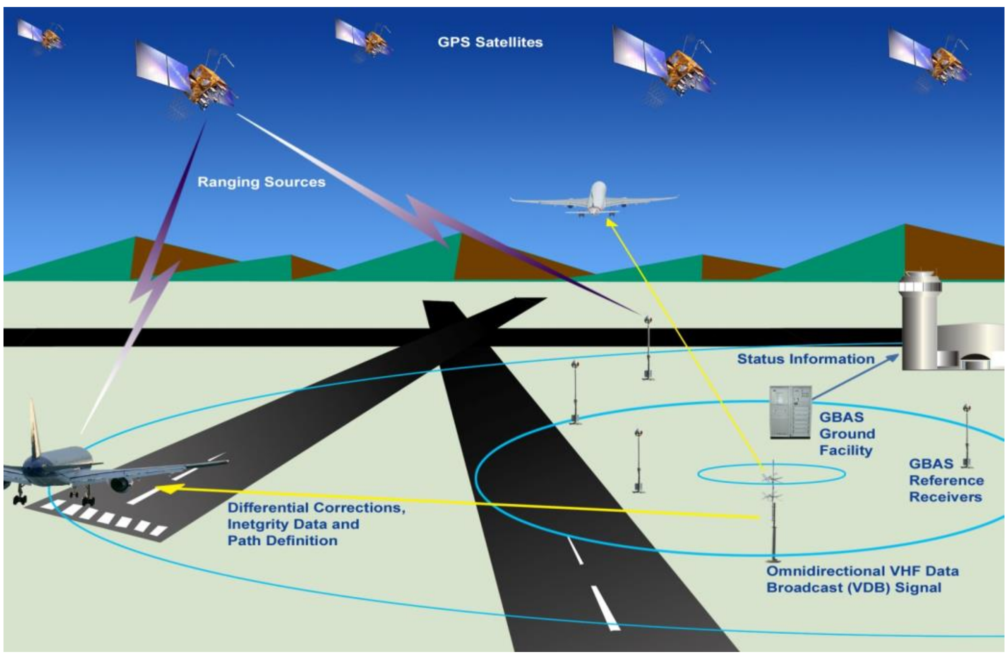

Figure 1 GBAS Architecture

Combining new SatNav and cockpit based technologies will improve safety, capacity, and efficiency at airports nationwide. Such technologies enable, through increased availability of precision approaches and efficiency of runway operations, an increased number of departures and arrivals during instrument meteorological conditions (IMC), approaching numbers closer to those possible during VMC operations. Taxi path depictions supporting low visibility surface operations, including the guidance and control enabling navigation function (D-Taxi/Surface Movement Guidance and Control (SMGC) may require the accuracy GBAS can provide. High density airports will be transformed through increased availability of information to both air traffic controllers and pilots - advances made possible through ADS-B equipment; GBAS positioning, navigation, and timing (PNT) services; and future possible virtual tower operations.

2 CURRENT OPERATIONS AND CAPABILITIES

The desired mode for terminal and approach operations is the use of integrated area navigation operation for the pilot to be seamless and transparent. As the aircraft proceeds from the en route environment to the terminal environment and onto the final approach path, it uses RNAV/RNP, vectors to final or other navigational means.

Final approach requirements are determined by weather conditions; CAT I, II, III service is provided by the Instrument Landing System (ILS) while SBAS (WAAS) can provide the guidance for departure, en route, terminal, and approach and landing (LNAV/VNAV/ LP, LPV and LPV-200). For users not equipped with SBAS, GPS RAIM will continue to be used as the RNAV source to capture the precision approach final (ILS).

While there are various implementations of SBAS avionics (equipment classes) the expectation is that users will make use of WAAS and RNAV capability to the maximum extent possible. For example, users of SBAS equipment class I will use SBAS to conduct en route, terminal and non-precision approaches. Class I equipment does not provide vertical guidance. In this case, users will be using barometric-VNAV for vertical in the terminal area. Similarly, those users with equipment class III will take advantage of its capability to support en route, terminal and approach operations to include LNAV, LNAV/VNAV, LPV, LP, and “LPV-200”. Detailed information on SBAS equipment class definitions and their capabilities can be found in RTCA/DO-229D, Minimum Operational Performance Standards for Global Positioning Service/Wide Area Augmentation System, December 2006. A similar discussion for the GPS/ABAS equipment class can be found in TSO-C129, Airborne Supplemental Navigation Equipment Using the Global Positioning System (GPS), 2/20/96.

Current plans for WAAS and GBAS equipage vary significantly between air transport and general aviation aircraft. The air transportation community considers GBAS as their choice for CATI, II, and III operations, their preferred operations are RNAV/RNP operations to a GLS final. All new generation Boeing and Airbus aircraft will be GBAS capable, GBAS avionics are either an option or in Boeing’s case come as standard equipment on certain aircraft models (B787, B737 MAX, B777XXX and B747-8).

GBAS is the SatNav solution to replace ILS and improve operations in the terminal area. The next chapter will address in detail current precision approach operations with ILS from different viewpoints - technical, ATC, the pilot’s perspective, and ILS shortfalls.

2.1.1 Current Supporting Infrastructure

The FAA sustains over 1200 ILS facilities dedicated to supporting navigation. This supporting infrastructure is made up of a mix of the following equipment (status 5/26/2016, FAA Instrument Flight Procedures (IFP) Inventory Summary):

IAP	by Lines of Minima
GLS ~	11
ILS	1,562
ILS (CAT II)	40
ILS (CAT II-III)	120
ILS (CAT III)	1
ILS PRM	36
ILS SA (CAT I)	99
ILS SA (CAT I-II)	30
ILS SA (CAT II)	8
Localizer Performance with Vertical guidance (**LPV**) approach GPS /WAAS	3694

Table 2: Current Infrastructure

3 DESCRIPTION OF CURRENT PRECISION APPROACH OPERATIONS

3.1.1 ILS Technical Perspective

The ILS provides precision approach guidance for aircraft. The elements of the ILS are the glide slope, localizer, and marker beacons. On board aircraft pilots navigate the approach with the Course Deviation Indicator (CDI). The ground equipment of the ILS system consists of localizer and glide slope antenna and a small building on the airfield that houses the equipment and marker beacon sites.

The following technical documents are providing guidance on ILS:

- ICAO Annex 10 is the main reference guide for technicians with regard to ground subsystem signal quality and positioning of antennas of ILS systems.
- ICAO DOC 8071 defines flight check issues of ILS-Systems.
- RTCA MOPS (DO-195 and DO-192B) for the Airborne ILS Localizer and Glide Path receiving equipment respectively and ARINC 710-10 for on board equipment

The ILS system is installed in the runway area and is subject to multi-path effects which place restrictions on building development and also on aircraft movements in the airport.

ILS Critical Areas are designed for protection of the ILS equipment. Protected areas are defined for both, the ILS Glide Slope and the ILS Localizer. Together, these protected areas are commonly referred to as the ILS critical areas. The critical areas are, therefore, protected when instrument approaches are being conducted with ceilings less than or equal to 800 feet or visibility is less than or equal to 2 miles.

Disruption of the ILS signal can lead to problems, such as:

- Misalignment of the course
- Disengaging of the arriving aircraft's autopilot
- Oscillatory error causing the plane to S-turn

In low visibility conditions the flight crew is required to use on-board automation (i.e. autoland) for approach and landing that are highly dependable on the ILS signal. Due to the technical nature of the ILS signal the ILS protection areas become larger in low visibility and aircraft entering the runway areas are required to hold on the CAT III holding points as opposed to CAT I holding points, which are closer to the runway and used in good visibility. This results in restricted ground movements and greater final approach spacing margins between aircraft in order to accommodate the subsequently longer runway occupancy times (ROT). The ILS CSA should not be penetrated by vehicles or aircraft in the airports during low visibility operations to ensure accuracy and integrity of the ILS. The following is required:

- All vehicles and aircraft on ground must remain outside the ILS Critical Area when the aircraft on final approach has passed the outer marker [Annex 10, Vol. 1, Attachment C)] ;

- ILS Sensitive area must be cleared before the controller can issue landing clearance to the following aircraft when the approaching aircraft reaches a defined distance to threshold typically 2 NM). Exceptionally the landing clearance can be delayed until 1NM providing that the position of the approaching aircraft can be monitored and the pilot has been warned to expect a late landing clearance.

- When departing aircraft are using the same runway as arriving aircraft, it is essential that the aircraft taking off has passed over the ILS localizer antenna before the arriving aircraft reaches a point on the approach where the interference caused by the overflight will have a critical effect. The aim should be for the departing aircraft to pass over the ILS localizer antenna before the arriving aircraft reaches a point 2 NM from touchdown or before landing clearance can be given to arriving aircraft.

3.1.2 ATC Perspective

ATC commonly uses radar vectoring as an alternative to standard approach procedures in order to establish aircraft onto a final approach sequence. This would normally result in interception of the localizer (LOC) at a minimum of 10 NM from touchdown, although interceptions at less than 10NM may sometimes occur.

With ILS CAT I operations, ATC operations have some constraints:

- When switching opposite runway ends, there is a need to wait until the last aircraft has landed on one runway before aircraft may commence an approach, using ILS, to the opposite runway since the interlock system prevents the two opposite approaches radiating at the same time. The controller usually has the option to switch off each of the ILS independently.
- ILS critical areas are established for an area of defined dimensions about the localizer and glide path antennas where vehicles, including aircraft, are excluded during all ILS operation. Critical areas affect departure and arrival efficiency.

Below are present ILS ATC interface functions:

- The ILS system status is continuously indicated to the responsible approach/tower controllers
- ILS status monitor can be a simple solution like an annunciation of requested category and a two colour indication where the colours green and red indicate whether the systems can be used or not.
- The complete ILS system status is normally only accessible to the maintenance team because it is not necessary for ATC.
- In case of ILS failure, ATC must inform the aircraft which are already on radar vector, standard procedure or transition and prepared for ILS that they have to prepare for alternate approach procedures or possibly for approach on an alternate runway.

3.1.3 Pilot Perspective

Instrument Approach Procedures (IAPs) using ILS
Published procedures are in place and which utilize ILS systems to support arrivals during poor weather conditions. Separate IAPs are published for each of the different CAT I, CAT II, and/or CAT III conditions.

For approach preparation, the pilot has to either switch the frequency of his radio management system to the frequency given on the approach plate, or select the approach from the FMS database. Proper reception of the correct ILS-signal must be identified (Morse code identification), so the pilot can identify whether or not the correct frequency has been selected. Since the identification signal consisting of letters using the Morse code is only transmitted on the localiser carrier, the ident notifies the pilot that the localizer is operating in normal mode. Some systems decode the signal and display this visually on the pilot's Primary Flight Display (PFD). Listening to the radio signal is not required in this case.

3.1.4 ILS Shortfalls

Technical Limitations

- Interference by Frequency Modulation (FM) broadcast
- Beam distortions due to construction at the airport
- Spectrum availability/ Number of channels
- One fixed glide slope
- No selectable thresholds

- False courses inherent in the signal
- Require two big antenna arrays per approach/runway end
- Channel pairing with Distance Measuring Equipment (DME) complicates spectrum allocation
- Due to the fact of ILS deviations capture performance can be dependent on the distance from the threshold; very short final segments may not be feasible
- Positional accuracy decreases further from the runway threshold

Signal Quality

The quality of the signal affects the way sensors process data and produce Navigation Sensor Error (NSE). Some examples are:

- False glide path
- ILS signal distortions outside the Final Approach Fix (FAF) can cause the aircraft to wander around the centreline but it appears to the pilot that the aircraft remains on the approach path and within the Normal Operating Zone (NOZ).
- Multi-path effects or signal distortions from other aircraft
- Limitation on support of low visibility takeoff

Potential Impacts

ILS shortfalls can have potential impacts, which may be categorized by one of the following categories:

- Operational – the operational shortfall includes the anticipated increases in cost and/or delays associated with the FAA's predicted 2% increase in capacity requirements coupled with ILS' current inability to fully utilize currently available runways. The additional or unexpected operational costs, which may include the time and cost of the flight crew, passenger delays, and flight cancels and/or diverts.
    - Minor path wander, longer flight time
    - Crew time / costs
    - Departure delays
    - Taxing delays

- Safety – the shortfall may result in safety issues such as blunders or near misses.
    - Wake turbulence
    - Overshoot; missed approach
    - Autopilot disengage; missed approach

- Reduced Functionality – the shortfall may result in certain desired functionality not being available. Reduced functionality may be seen as a reduction in operational potential.
    - Cannot use certain runways
    - No curved path final approaches
    - No constant descent
    - No staggered glide slope
    - Increased separation needed due to signal masking by leading aircraft

- Availability – the shortfall may result in the system being unavailable during otherwise desirable times, which could therefore lead to reduced operational potential, and the costs of cancelled and/or diverted flights. Additionally, systems at the end of life cycles will include: obsolescence – with diminishing vendors and sources of supply; increased frequency of MTBF – with increased costs of unscheduled maintenance; delays – outages of ILS equipment will even further delay flights.

- System outages, cancelled / diverted flights
- Unplanned costs to model airport / local building changes
- Unscheduled maintenance costs to resolve ILS signal / system issues

4 JUSTIFICATION AND DESCRIPTION OF CHANGES

GBAS will eliminate the capacity constraint placed on air traffic operations due to the ILS critical areas. A single GBAS system will be capable of providing precision approach capabilities to multiple runways. It can be installed at airports that do not have precision approaches due to ILS siting constraints and will satisfy the need to provide all-weather approach and landing as well as surface navigation capabilities with significant improvements in service flexibility, safety, and user operating costs. High density terminal airspace of the future will provide continuous descent approaches followed by positive guidance to the gate in extremely low visibility conditions. This capability will require high precision and integrity satellite-based navigation and landing service, 4-dimensional air traffic automation, secure digital data-link and cockpit automation. GBAS technology will be essential for the implementation as an enabling technology.

GBAS provides the following services and changes:

- ***CAT IIIa/b Precision Approach and Autoland:*** GBAS is capable of providing Category I, II, III precision approach, autoland capability and rollout guidance. GBAS GAST D service is intended to facilitate CAT II, CAT IIIa and IIIb operations. Additional augmentation on the aircraft is required to complete CAT III and autoland operations. Typically this includes an automatic landing system and/or heads up display. It is desirable that GBAS is capable of supporting autoland operations, independent of the category of service provided by the ground facility. The purpose of this is to enable autoland operations in VMC conditions on as many runways as practical. Autoland aids in achieving stabilized approaches, consistent touchdown performance, and pilot training for CAT III.

- ***CAT I, II, and III precision approach guidance for multiple runways with a single facility –*** currently, an ILS facility is required at each runway end in order to provide precision approach service to that runway. Enhanced navigation equipment will be able to provide precision approach capabilities to multiple runways, including those not currently served by ILS.

- ***GBAS Siting Flexibility:*** GBAS provides precision approach capability where siting constraints (terrain and obstacle) have prevented ILS from being implemented. The GBAS equipment is not fixed by function like ILS equipment, which has to be located at the respective runway ends. This provides flexibility in locating the GBAS components on the airport; however, the GBAS equipment should be located on airport property, preferably within the Airport Operations Area (AOA). Key factors for antenna location are sky obscuration, the reception of satellite signals and multipath, reception of reflected signals caused by local stationary objects, potential radio interference, and taxiing aircraft. Siting restrictions and procedures are GBAS Siting Criteria are laid out in Order 6884.1

- ***Increased access where ILS siting constraints exist –*** provide precision approach capability where siting constraints (terrain and obstacle constraints) have prevented ILS from being implemented.

- ***Elimination of ILS Critical Areas –*** ability to eliminate operational restrictions due to ILS critical areas and a reduction in ground movement delays. Current ILS operations suffer from a number of limitations. ATC is required to protect the critical areas to prevent disturbance of the ILS signal. The critical area requires CAT I/II/III holding positions to be established further from the runway. The critical area must be clear before the controller can issue landing clearance to a following aircraft. The size of the critical area considerably restricts runway capacity during periods of CAT I/II/III operations. The Sensitive Area (SA) requires CAT I/II/III holding positions to be established further from the runway. The SA must be clear before the controller can issue landing clearance to a following aircraft.

- ***Use of advanced procedures (RNP to GLS) to increase capacity and efficiency –*** provide low visibility access and increases operational efficiency and single and multiple runway capacity through the use of GNSS.

- ***Increased flexibility for terminal ATC operations –*** ability to allow for predictable flight paths in the terminal area which could enhance pilot and controller situational awareness and potentially reduce communications workload and the variability in the time and distance flown in the terminal area and lead to more flexible routing.

- ***Reduced separation in arrival operations –*** ability to provide multiple individually selectable approach procedures to a single runway with different glide slope angles. Multiple approach procedures may be provided that have offset thresholds of different Glide Path Intercept Points (GPIP). A combination of offset thresholds and different glide-path angles can be used to larger and smaller aircraft to ensure the smaller aircraft will not be affected by the wake-turbulence generated by the larger aircraft. This capability supports reduction in separation by mitigating wake turbulence.

- ***Multiple or offset glideslopes mitigating wake turbulence:*** GBAS can provide multiple, individually selectable approaches to the same runway which may have different glide paths, as well as displaced thresholds. This capability may accommodate wake turbulence mitigation for arrivals for closely spaced parallel dependent operations. Multiple final approach segment definitions would be broadcast by the ground station, each associated with a unique channel number to enable selection of the desired procedure. Additionally, multiple approach procedures may be provided that have offset thresholds of different Glide Path Intercept Points (GPIP). A combination of offset thresholds and different glide-path angles might be used by larger and smaller aircraft to ensure the smaller aircraft will not be affected by the wake-turbulence generated by the larger aircraft. Additional research is necessary to determine if these capabilities can be exploited to provide reduced separation, especially in a mixed equipage environment. Different glidepath angles may be technically possible yet may have limitations due to operational and implementation considerations and may require special approvals. Anything larger than 3.77 degrees requires airworthiness approval (STC).

- ***GBAS characteristics facilitate Closely Spaced Parallel Runway Operations:*** GBAS has navigation system error characteristics that are largely linear and is an improvement over the angular errors associated with ILS. GBAS guidance becomes linear distance determined by the splay and runway length. Additionally the ILS signal is noisy, ILS signal distortions outside the final approach fix (FAF) can cause the aircraft to wander around the centreline but it appears to the pilot that the aircraft remains on the approach path and within the normal operating zone (NOZ). This usually occurs beyond 10 nm of the approach. GLS does not have that problem.

  Current GBAS approaches use the ILS Terminal Instrument Procedures (TERPS) surfaces. While this may be necessary for the initial transition from ILS to GBAS-based approaches, it may also limit the benefits to be gained. Precision approaches using TERPS surfaces designed specifically for GBAS may result in lower approach minima than are currently permitted when ILS-based surfaces are used and will provide increased accuracy and integrity for precision approaches during closely spaced parallel operations (CSPO).

- ***Departure guidance not available with legacy ILS –*** capability to support terminal area operations with extended service volume. This would also include support to advanced RNAV/RNP procedures, like guided departures, that are not available with legacy ILS.

- ***Support of aircraft and vehicle movement on airport surface –*** position data of aircraft and vehicles on the airport surface could be integrated with supplemental surveillance sensor data and input to terminal automation systems in order to provide accurate position information to pilots and ATC personnel. The position information allows for increased pilot and controller situational awareness of the airport surface environment such as runway status and location of nearby traffic. Controllers identify appropriate taxi routes to guide pilots and their aircraft safely to their on-airport destination. Overall airport surface movement is improved with resultant increases in capacity.

- ***The Department of Defence and GBAS:*** The DoD plans to leverage FAA GBAS development for their Joint Precision Approach and Landing System (JPALS) program. Civil interoperability is a “Key Performance Parameter” to this DoD system.

5 GBAS CONCEPT OF OPERATIONS

The GBAS Concept of Operations (CONOPS) addresses relationship to NextGen, capabilities and services, architecture, airborne system, service levels and equipment, procedure design and charting, operating procedures and training, and maintenance.

The GBAS CONOPS considers the following GBAS service volume requirements:

- Standard GBAS precision approach services (approach and autoland) to 23 nautical mile(s) (nm) (extension of Dmax to 30 nm desired for extended final approach operations) – initial GAST- D service based on existing standards
- Extended Service Volume
- DCPS for high accuracy and integrity navigation for RNP/RNAV operations in the terminal area to 60 nm – potential additional service
- DCPS for high accuracy and integrity navigation for surface operations – airport coverage - potential additional service

GBAS will support advancements in navigation performance in order to achieve NextGen improvements. GBAS is intended to provide satellite based CAT I/II/III precision approach and landing capability and DCPS suitable for RNAV and RNP based procedures. In the future, GBAS may support terminal area operations with extended service volume. The versatility of the airborne receiver and DCPS may support terminal RNP-RNAV procedures, including Departure Procedures (DPs), STARs, and curved and segmented approach paths.

GBAS will improve capacity constraints based on ILS infrastructure requirements. GBAS provides precision approach capability where ILS siting constraints (terrain and obstacle) have prevented a precision approach from being implemented. The GBAS equipment is not fixed by function like ILS equipment, which has to be located at the respective runway ends. GBAS is not limited by the operational restrictions due to ILS critical areas and can reduce ground movement delays.

The implementation of GBAS will reduce controller workload and reduce the capacity constraints caused by ILS critical areas. A standard GBAS approach is designed as an ILS look-alike without the constraints of the ILS. For terminal area operations, the combination of RNP and GLS permits more effective utilization of current airspace and procedures.

5.1 Assumptions and Constraints

The desired mode for GBAS operations is within an integrated area navigation operation that allows the instrument display to the pilot to be seamless and transparent. As the aircraft proceeds from the en route environment to the terminal environment and onto the final approach path, it uses RNAV/RNP or other navigational means until the aircraft is within GBAS coverage.

A combined SBAS/GBAS equipment can support operations from departure, en route to terminal and Cat I precision approach and landing. The GBAS equipment will support precision approaches including Cat I, II, III, and differential positioning service in some cases.

Table 1 summarizes the capabilities of GBAS, SBAS sensors, and aircraft based augmentation system (ABAS) such as GPS/RAIM as part of the GPS augmentation sensors. As shown in the table, while the SBAS equipment is the source of navigation for the en route phase of flight, the terminal operation could be supported by either equipment if the user is within the range of GBAS coverage.

Detailed information on SBAS equipment class definitions and their capabilities can be found in RTCA/DO-229D, Minimum Operational Performance Standards for Global Positioning Service/Wide Area Augmentation System, December 2006. A similar discussion for the GPS/ABAS equipment class can be found in TSO-C129a, Airborne Supplemental Navigation Equipment Using the Global Positioning System (GPS), 2/20/96.

Phase of Flight or Operation Type	Avionics Type (or Mode of Receiver Operation)						
		GPS/SBAS				GPS/GBAS	
	GPS/ABAS (Note 1)	Class-I	Class-II	Class-III	Class-IV	Approach Service	DCP Service (Note 4)
Departure						(3)	
Enroute							
Terminal							
GPS Approach	(2)						
LNAV							
LNAV/VNAV							
LPV							
CAT I							
CAT II						(3)	
CAT III						(3)	

Table 3 - Summary of GPS Augmentation Sensors and their capabilities

Note 1: Approval is limited as a supplemental means of navigation except for certain operation in oceanic and remote areas

Note 2: Depends upon avionics class and integration.

Note 3: Future capability of GBAS. Avionics updates may be required.

Note 4: The GBAS ground facility determines if this service is supported. Avionics capabilities beyond those defined in the GBAS MOPS are required to support these operations. For example, an integration of GBAS with an RNP or RNAV capability would be needed.

5.1.1 GBAS and ILS Look Alike

The reason for the implementation of GBAS is to provide additional capabilities and benefits not found with ILS; therefore, offering new operational opportunities to stakeholders. However, to ensure the most cost efficient implementation, GBAS development initially led to the GBAS "ILS Look-Alike" concept. Unfortunately, this choice limits some of the overall potential benefits of GBAS.

The logic behind the "ILS Look-Alike" concept was the following: The current flight deck architecture constraints imply that what is implemented on board today must be re-used as much as possible in the future. The goal was to remain as close as possible to what is done today with ILS regarding all aspects, such as:

- On-board system
- Interfaces
- Performance
- Procedures
- Control
- Training

From the ATC point of view, an ILS look-alike approach is considered to be operationally identical to an ILS approach to the same runway. This would mean that the final approach track is aligned with the axis of the runway (with a tolerance of ±5 degrees), and that the glide path angle is the same as the ILS (normally 2.5 to 3.5 degrees). It also means that the ATC operational procedures are the same, e.g. with ATC having the capability to vector the aircraft to intercept the final approach track at the same point as for the ILS.

From the flight operation point of view, the following example dealing with the "ILS Look-Alike" concept in aircraft manufacturer philosophy shows that this concept can be characterized with four elements:

- Operational: To ease the introduction of the new landing modes, the ILS Look-alike concept uses similar operational procedures for all landing functions so as to minimize the impact of the operation on ATS and the crew. The associated training is then reduced and the operational effectiveness is increased.

- Human Factors: The ILS beam concept has been used for 50 years by numerous pilots. As a consequence, the GLS function embedded in the MMR will compute pseudo-LOC and pseudo-GP deviations for display on the standard flight instruments.

- Performance: The airplane systems perform in a similar manner as for the ILS based landing operations, without some of the less desirable attributes of an ILS based operation (e.g. interference from departing or taxiing aircraft, false capture, scalloping).

- System Interfaces: By making the deviation outputs of the MMR similar to the ILS for the downstream systems such as autopilot, displays, etc, the impact on these aircraft systems will be minimal and the cost associated with certification are minimized.

5.1.2 GBAS – Potential future services

Some of the potential GBAS capabilities and benefits limited by the present GAST D (GBAS Approach Service Types, GAST D = CAT III equivalent) architecture are addressed below. GAST D architecture presently does not include GBAS services like differentially corrected positioning service (DCPS), airport surface operations.

5.1.2.1 High accuracy and integrity navigation for RNAV/RNP operations (Differentially Corrected Positioning Service (DCPS))

The standards for GBAS include two types of service. One type, the precision approach service, provides deviation information relative to a defined final approach segment path. The other type is the DCPS, which provides differentially corrected position inputs for use by flight management systems for a range of applications, including flying RNAV or RNP operations and providing high integrity accuracy position for ADS-B in the terminal area. GBAS DCPS within the terminal area enables GBAS equipped users to fly complex RNAV/RNP procedures with higher availability and reliability (Note: SBAS and GEO ranging also provides high availability for SBAS equipped users).

The primary use for DCPS identified was to provide a position velocity and time output to drive other systems. The most significant would be to send the PVT and associated characterizing error bound numbers into an aircraft FMS. The DCPS benefit identified was availability. New generation aircraft are typically approved for RNP 0.11 and 0.15 using GPS Receiver Autonomous Integrity Monitoring (RAIM) and a blended solution of other available navigation measurements. RAIM Fault Detection and Exclusion (FDE) require the use of six satellites. FAA SATNAV implementations, both WAAS and GBAS, provide integrity, eliminating two of the solution unknowns, thereby providing additional availability margin by reducing the number of required satellites from six to four.

DCPS is currently not approved in existing GBAS CAT I systems; different concepts exist for DCPS to be implemented in the CAT II/III GBAS system architecture. However, operations and performance characteristics (integrity and continuity) need to be defined for DCPS to be integrated into the architecture.

5.1.2.2 Airport Surface Operations

For airport surface operations DCPS, with avionics augmentation, would enhance the performance of moving map displays and display of own-ship position. Future applications such as Taxi path depictions supporting low visibility surface operations, including the guidance and control enabling navigation function (D-Taxi/SMGC), will likely require greater accuracy, integrity and availability than can be achieved with GPS alone. Significant future safety enhancements such as runway occupancy detection and alerting will probably require DCPS for improved accuracy, integrity and availability, not only for own ship positioning and navigation but for ADS-B reporting.

5.1.2.3 Guided Take-off

The main objective in using GLS (like ILS) during Guided Take-Off is to get a RVR reduction. Guided Take-Offs are only authorized if the aircraft is equipped with an approved lateral guidance system and an operational approval has been obtained. Such systems are currently all head up displays, providing the pilot flying with a lateral guidance by using information from the landing aid. Since Guided Take-Off operations still require visual cues the only requirement for the SIS is to have a CAT III accuracy performance. Since GBAS accuracy is not any different from ILS, a GBAS ground station can be used for Guided Take-Off operations. From aircrew operation viewpoint, the new GLS guided take-off operating method will be identical to ILS guided take-off operating method,

GBAS lateral deviation data would be needed on the runway, to support the Guided Take-Off mode. The take-off modes initially uses lateral deviation as in the post landing roll-out mode. The RWY guidance mode gives lateral guidance orders during takeoff, and initial climb. The RWY guidance law aims at maintaining the aircraft on the runway centerline during the take-off run, and on the LOC beam when the aircraft is airborne. To do so, RWY mode provides the FD yaw bar order. The yaw bar is only available if the runway has a LOC aligned with the runway centerline. RWY mode arms when the aircraft approaches the runway threshold. When the flight crew sets the thrust levers to FLX or TOGA for take-off, RWY mode engages, and the yaw bar appears on PFD and HUD. The yaw bar indicates the correction that the flight crew must apply to the rudder pedal, in order to move the aircraft to the runway centerline. The LOC deviation symbol indicates the position of the aircraft in relation to the runway centerline. The combination of both helps the flight crew perform an accurate take-off roll. Guidance subsequent to take-off is usually FMS coupling. Many AFCS installations allow arming of the FMS guidance at take-off, so that capture takes place at a preset altitude. Therefore, GBAS lateral deviation data would be needed on the runway, to support the Guided Take-Off mode. An alternative (diverting from ILS look-alike concept) would be for RNP guided take off operations based on GBAS signals.

5.2 Operational Environment

5.2.1 Envisioned capabilities of the proposed operational concept

The desired goal for terminal and approach operations is the use of integrated area navigation operation seamless and transparent for the pilot. As the aircraft proceeds from the en route environment to the terminal environment and onto the final approach path, it uses RNAV/RNP, vectors to final, or other navigational means. Final approach requirements are determined by weather conditions; CAT I, II, and III service will be provided by GBAS. SBAS (WAAS) can provide the guidance for departure, en route, terminal and approach, and landing (LNAV/VNAV/ LP, LPV and LPV-200). This chapter discusses GBAS capabilities, ground facility operations and specifics, ATC interface, and aircraft interfaces.

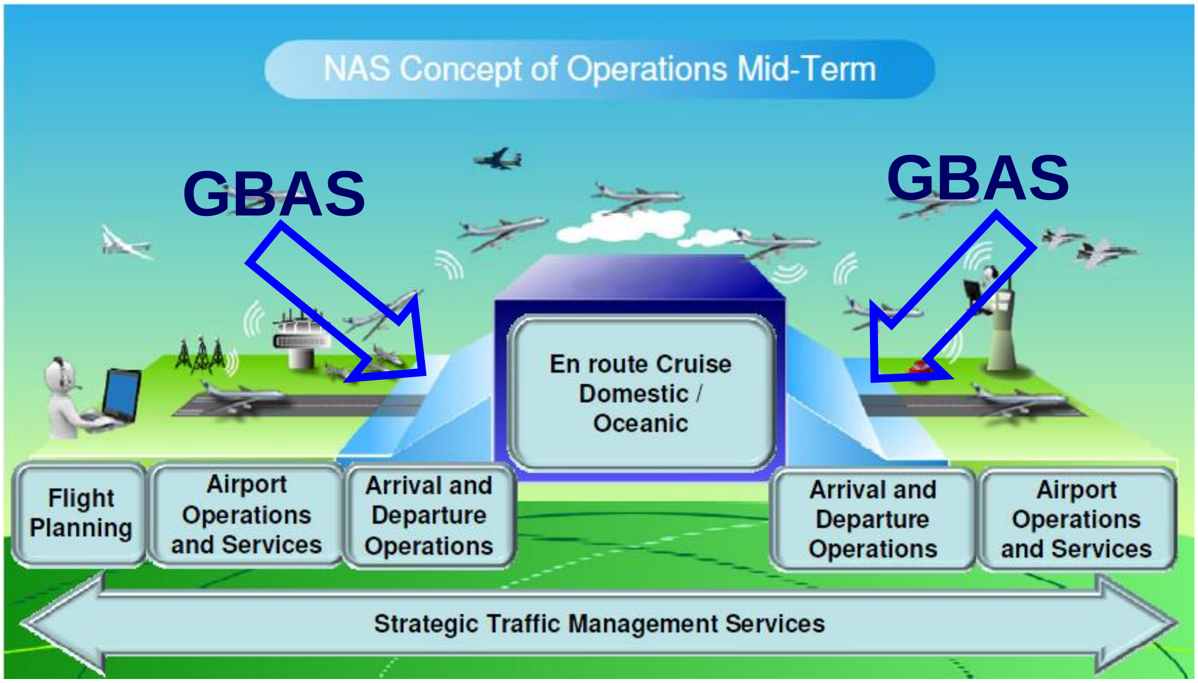

Figure 2: GBAS and NAS Operational Environment

5.2.2 GBAS Operational Capabilities

GBAS will support advancements in navigation performance in order to achieve NextGen improvements. GBAS is intended to provide satellite based CAT I/II/III precision approach and landing capability and DCPS suitable for RNAV and RNP based procedures. In the future, GBAS may support terminal area operations with extended service volume. The versatility of the airborne receiver and DCPS may support terminal RNP-RNAV procedures, including Departure Procedures (DPs), STARs, and curved and segmented approach paths.

GBAS will improve capacity constraints based on ILS infrastructure requirements. GBAS provides precision approach capability where ILS siting constraints (terrain and obstacle) have prevented a precision approach from being implemented. The GBAS equipment is not fixed by function like ILS equipment, which has to be located at the respective runway ends. GBAS is not limited by the operational restrictions due to ILS critical areas and can reduce ground movement delays.

5.2.3 Systems, services, procedures, and technologies that comprise the envisioned environment

5.2.3.1 GBAS Ground Facility

The GBAS consists of three separate segments; the Ground Facility, the Space Segment, and the Airborne Subsystem. GBAS uses a VHF Data Broadcast (VDB) in the band 108 to 117.975 MHz to communicate between the ground and airborne systems. The ground facility provides differential corrections, integrity parameters, and precision approach path point data referenced to the airport coordinate system, thus defining the path in space to enable the precision approach operations broadcast via a Very High Frequency (VHF) Data Broadcast (VDB) to the Airborne Subsystem for processing. The Space Segment provides the GBAS ground facility and Airborne Subsystem with GPS ranging signals and orbital parameters. The Space Segment also provides the ground facility and Airborne Subsystem with optional Satellite-Based Augmentation System (SBAS) ranging signals and orbital parameters. "The Airborne Subsystem applies the ground facility corrections to the GPS and SBAS ranging signals to obtain a corrected position with the required accuracy, integrity, continuity, and availability when within the operational service volume of the ground station. The corrected position is used within the GBAS avionics, along with path point data, to supply deviation signals to drive appropriate aircraft systems supporting terminal area and precision approach operations. The position output also provided by the GBAS avionics increases the capability of aircraft equipped with RNAV/RNP via the higher availability and accuracy of the GBAS solution. The ground facility provides detailed status information to support maintenance and air traffic requirements.

5.2.3.2 Maintenance and ATC Interface

The ground subsystem control and status functions are designed to support the requirements of local maintenance staff and air traffic control (ATC). Status and control capabilities are executed through a Maintenance Data Terminal (MDT). Additionally, status information is provided to ATC via an Air Traffic Status Unit (ATSU) interface and within the ground subsystem equipment shelter via the Local Status Panel (LSP). The following status information should be provided:

- Modes and Service Alerts
- Aural signal annunciations for service alerts and when the system is not available (alarm condition)
- Silencing alerts and alarms (manually) upon command

The purpose of the MDT is to command and monitor all test and maintenance actions available through a maintenance interface.

Local procedures should be in place for maintenance coordination, especially for removing equipment from service and returning it back into service. These procedures will call for coordination between the tower controllers and the maintenance staff for any GBAS performance changes. These procedures will mirror the current ILS controller/maintenance procedures.

GBAS implementations within the NAS will transmit all approved approaches at all times, including when a particular runway may not be active. GBAS provides options with regard to disabling non-operational approaches within the uplink, maintaining the ability to disable specific approaches in case of runway closure. Further options may be considered for specific runway configurations and runway usage concepts. GBAS allows, in principal, multiple approaches to be simultaneously broadcast for the same runway end when desired. Only approach procedures designed and approved in accordance with current FAA procedure rules can be loaded in the GBAS for uplink.

5.2.3.3 Ground Installation

The ground subsystem includes a number of components, including but not limited to

- Multiple GPS antenna and receiver assemblies
- Single or Multiple VHF antenna(s) and transmitter(s)

- A central equipment rack for all data processing
- Backup power system (e.g. batteries)

The equipment rack must be located in an environmentally controlled NAS Equipment Building (NASEB). Normally, the VHF transmitters and backup power subsystems will also be located in the same building. GPS antennas, GPS receivers and VHF antennas will be located at a variety of locations on the airport and generally are not located in a building. Their functions require them to be exposed to the elements. In some cases, it may be necessary to install secondary VHF antennas and transmitters at locations far from the central equipment rack and NASEB.

For the initial identification of potential ground equipment sites, the evaluation process has to consider physical and environmental impacts, interference and survey requirements..

With regard to the reference receivers, a set of key factors has to be considered for antenna location:

- Sky obscuration: The reception of satellite signals requires a direct line-of-sight between antenna and satellite which must be free of obstructions (mobile and fixed obstacles);
- Multipath: Multipath effects (reception of reflected signals) can be caused by stationary objects, ground vehicles, and taxiing aircraft. The consideration of multipath effects is one of the key factors for site selection;
- RFI: The GBAS ground equipment will be required to detect hazardous levels of RFI. The use of GPS Privacy Jammers IS a growing concern for GPS related services. GBAS siting needs special attention to minimize the operational impact of these mobile jammers

Further requirements have to be considered with regard to the availability of precisely surveyed coordinates, flexure, antenna orientation and separation, and the impact of the reference receivers on the critical areas of other systems. For example, the antenna mounting height requires careful consideration since the optimum compromise between sky obscuration (the higher the better) and multipath (the lower the better) has to be found.

The location of the VHF transmit antenna should be chosen under consideration of the following issues:

- Obstacle restriction criteria;
- No impact on existing equipment, sufficient distance to critical areas;
- The radiated signal should be as unobstructed as possible (ideally unobstructed line of sight);
- Sufficient field strength in the whole coverage area (antenna height).

An installed GBAS is required to monitor its environment to determine if the transmitted data remains within the operational tolerances. These monitors are largely statistical and certain routine operations, such as grass cutting, may trigger these monitors if required maintenance practices are not observed.

During installation of the GBAS station, the local environment is sampled to assess the impact of both multipath and radio-frequency interference. Multipath is the reflection of valid GPS signals towards the reference receivers from a surface near the reference receiver. Multipath can decrease the accuracy and integrity of the GBAS station if not mitigated. Radio-frequency interference (RFI) is the intentional or unintentional broadcast of a non-GPS signal in the GPS frequency spectrum. RFI can also reduce the accuracy and integrity of the GBAS station if not mitigated. The siting criteria and initial installation develop conditions that minimize the multipath environment. The siting criteria determine locations in which there is minimal to no RFI. Station settings are designed to shut down the station prior to a loss of station integrity in the event multipath or radio-frequency interference increases over the levels measured at installation.

Maintenance of the local environment plays a key role to control the station multipath environment. The station installation developed station errors based on expectations of ground surface and foliage growth in the vicinity of the reference receivers. It is important for the continuity of the station to maintain the conditions established at site installation. Construction the vicinity of the airport that either changes the GPS signal multipath propagation or that interference with direct observation of low-elevation GPS satellites might require re-measurement of station specific parameters and might limit station availability from that initial established. During airport maintenance activities, it is important to limit extraneous L-band emissions from maintenance personnel (e.g. radios). It is necessary to maintain and repair fencing or barriers designed to block interfering signals. If station operations become adversely affected, it might be necessary to monitor the local radio-frequency spectrum and identify interference sources. For sources that cannot be removed, it might be necessary to develop additional mitigation methods, such as barrier construction or reference receiver relocation.

The station will shut down to protect supported aircraft when it detects and increase in multipath or RFI. If neither the cause of the increase in multipath nor the source of RFI can be quickly mitigated, the maintenance procedures should include steps to remove the affected procedures from operational status.

5.2.3.4 GBAS Airborne Implementation

Presentation (or display) of GBAS guidance to the pilot is delivered via existing CDI, HUD, etc. equipment similar to today's ILS. The crew procedures and flight deck controls and displays are designed to be as similar as possible to ILS. Some minor differences exist. For example, the GBAS-specific Reference Path Identifier (RPI) may be visually displayed on the Primary Flight Display. The RPI aural identification replaces the ILS aural identification. The display of the RPI indicates that the VDB transmission was successfully received, decoded and verified to be complete, and the messages are being processed for the selected approach. It has to be taken into consideration that the presence of the RPI only indicates that matching FAS data was loaded and that the equipment is operating in normal mode (Message Block Identifier).

In contrast to ILS, GBAS always indicates the distance to the threshold or fictitious threshold point. This is similar to DME distance, which displays the distance the aircraft is from the DME antenna (typically the localizer antenna), which is at the far end of the runway up to 2 or more miles from the TDP. GBAS will indicate the aircraft's distance to TDP/FDP via the aircraft’s existing instrumentation, i.e. the same location that the DME is currently being displayed.

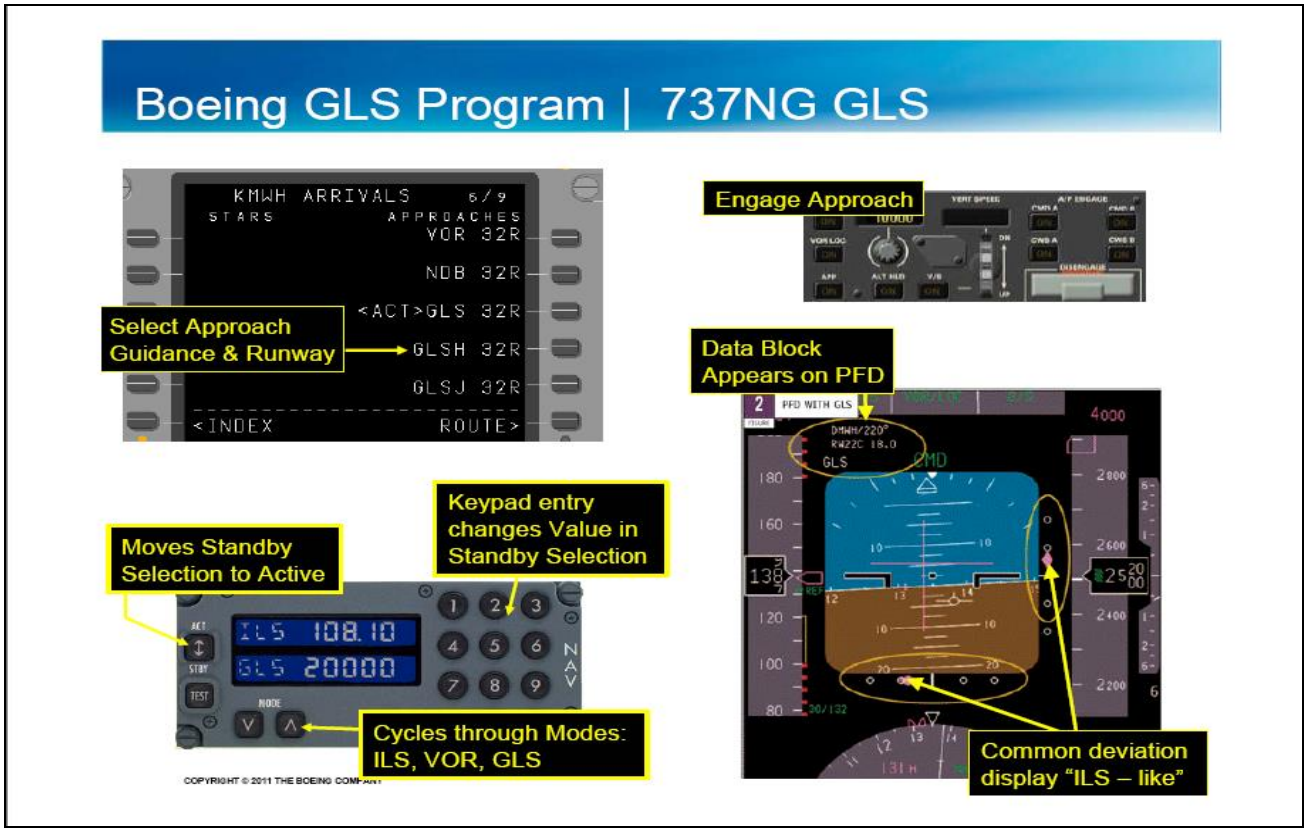

Figure 3: Example Boeing 737 GLS integration

5.2.3.5 GLS Independence from FMS

For the FMS, the ILS, or GLS are precision approach guidance functions with basically no bearing on FMS functionality (other than facility selection, background data and possible use of GLS data for position updating). Either the FMS steers the aircraft (in LNAV, VNAV) or the GLS guidance steers the aircraft (in APP/LAND).

The FMS is the aircraft 4D area navigator and economy optimization system. It is capable of being coupled with the AFCS for guided flight control from immediately after take-off (or go-around), until interception of the precision approach, either fully or partially coupled (i.e. all or single axis). FMS guidance is coupled to the AFCS via the LNAV, VNAV and auto throttle functions; these are 'single' (not redundant) AFCS modes of operation, consistent with the approved operational envelope of the FMS.

As it stands, there is no interface from the MMR to the FMS for the FMS to receive data from the GBAS VDB transmissions. This means that path points from GBAS cannot be imported into the FMS. For the FMS, GLS should be no different than ILS; data from the MMR VDB cannot be imported into the FMS for introduction into the trajectory definition.

5.2.3.6 Approach Selection

Each GBAS approach is assigned a 5-digit channel number that encodes both the physical VHF frequency of the VDB transmission and a Reference Path Data Selector (RPDS) which indicates the specific FAS datablock to be used to compute the reference path for the guidance. The GBAS channel number is provided to the GBAS airborne equipment (e.g. the Multi-Mode Receiver (MMR)) in one of two ways: by pilot entry of the channel number through a dedicated control head, or via the FMS line select key associated with the name of the approach (e.g. GLS 32L).

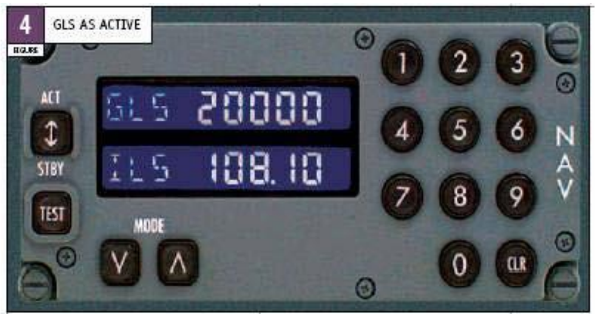

Figure 4 - Multi Navigation Control (Boeing Implementation)

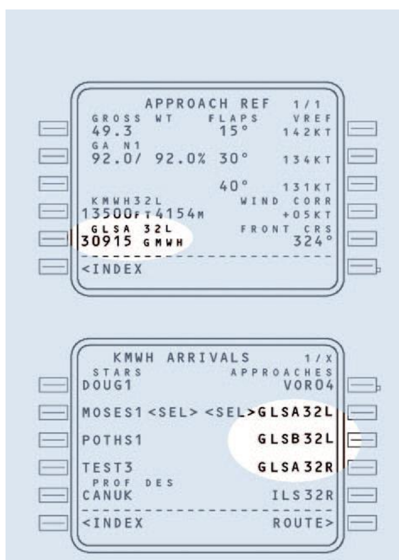

Figure 5 - FMS Multifunctional Control Display Unit

As soon as the correct VDB transmission is received, decoded and valid messages are being processed, the RPI (which is part of the FAS data block) of the selected GBAS approach is shown on the primary flight display (PFD). Standard operating procedures require that the RPI of the GBAS approach be cross-checked against the data from the approach chart before starting the final descent. (This is analogous to the pilot checking the ILS ident during an ILS operation). RPIs may still be implemented aurally into older avionics suites.

Capture of a GBAS approach is identical to capture of an ILS approach. Prior to capture, the aircraft is being flown based on another source of guidance. The approach mode is "armed" and the autopilot monitors the guidance (deviations) and airplane heading to determine when the approach is captured.

5.2.4 Operating environment, affected users, organizations, and corresponding roles and responsibilities.

5.2.4.1 Air Navigation Service Providers

As with any new navigational aid, there needs to be careful frequency allocation to avoid interfering with established navigation facilities. Consideration must also be given to the local navigation database for relevant information to cover GNSS input signal, augmentation process, broadcast signal output and signal interference. As with other ground based navigational aids, a data monitoring sub-function is required to allow ATC to monitor the status of the GBAS. The air navigation service provider or owner of the non-federal GBAS is responsible for:

- Issuing NOTAMs in case of malfunctions of ground equipment and inadequate performance of GPS signal within a specified period and determine the appropriate outage time and add that time to these requirements
- Up-to date databases for the ground subsystems
- Switching on and off the broadcast approach paths
- Coordination for maintenance outages of ground subsystems
- Alerting tools for malfunctions of ground subsystems or inadequate GNSS signal

5.2.4.2 GBAS Aeronautical Information Publication (AIP) specifics

The AIP contains aeronautical information essential to air navigation. It is designed to be a manual containing thorough details of regulations, procedures, and other information pertinent to flying aircraft in the particular country to which it relates. It is usually issued by or on behalf of the respective civil aviation administration. The following information on GBAS should be provided in the AIP:

- AIP facility classification
    - Ground facility performance type
    - Ranging source types (GPS)
    - Facility coverage: 23NM for Approach from the VDB antenna,
    - Polarization type (horizontal or elliptical)

- AIP Approach classification:
    - GBAS Ground Station Identifier (link to the facility capability)
    - Runway end (FPAP) dealing with runway physical characteristics
    - GBAS coverage limit
    - VDB channel Number
    - Database channel number

- Autoland capability (requires publication of extended GBAS signal coverage down to 12 ft)
- GBAS approach charts with associated channel number

5.2.4.3 New approach service classification (ICAO concept)

GBAS approach services are differentiated into multiple types referred to as GBAS Approach Service Types (GAST). GAST is defined as the matched set of airborne and ground performance and functional requirements that are intended to be used in concert in order to provide approach guidance with quantifiable performance. Four types of approach service, GAST A, GAST B, GAST C, and GAST D are currently defined. GAST A and B are intended to support levels of service which are not currently planned for use by GBAS within the US NAS. GAST C is intended to support typical CAT I operations. GAST D has been introduced to support landing operations in lower ceiling and visibility conditions including CAT III operations. The FAA acquisition milestones within NextGen support a GBAS ground subsystem that could support GAST C and GAST D simultaneously. Current avionics only supports a single type of approach service, GAST C.

5.2.4.4 Ground Facility Configuration (GFC) - Performance

ICAO SARPS classifies a GBAS ground facility according to key configuration options. A GFC is composed of the following elements:

a) Facility Approach Service Type (GAST A, B, C, and/or D)
b) Ranging Source Types (G1 – GPS, G2 – SBAS, G3 – GLONASS, G4 - Reserved for Galileo, G5+ - Reserved for future Ranging Sources)
c) Facility Coverage (min 23nm – maximum 60nm (based on average terminal area definition))
d) Polarization (elliptical or horizontal – assumption for Horizontal)

Airports in the US NAS will have multiple service requirements and capabilities, CAT I/II/III requirements will have to be met and systems have to be backwards compatible. GPS and SBAS-based configurations are the preferred option for NAS GAST C and GAST D configurations:

– CAT I operations - Ground facility classification example: ***GFC C/G1G2/23 (minimum)-60(maximum)/H*** - (Ground facility/ GAST C / GPS and SBAS / Min 23nm-max 60nm / horizontal polarization)
– CAT I/II/III operations - Ground facility classification example: ***GFC CD/G1G2/23 (minimum)-60(maximum)/H*** (Ground facility / GAST C and D / GPS and SBAS / Min 23nm-max 60nm/ horizontal polarization)

GPS only based configurations may be encountered based on the proliferation of GBAS non-Federal systems, which presently do not include SBAS availability:

– CAT I operations - Ground facility configuration classification example: ***GFC C/G1/23 (minimum)-60(maximum)/H*** - (GAST C / GPS / Min 23nm-max 60nm / horizontal polarization)

– CAT I/II/III operations - Ground facility classification example: ***GFC CD / G1/23 (minimum)-60(maximum)/H*** – (GAST C and D / GPS/ Min23nm-max 60nm / horizontal polarization)

5.2.4.5 Approach Facility Designations

A GBAS ground station may support many approaches to multiple runway ends. However, it is possible that a GBAS may support multiple approaches to the same runway end with different Types of Service (intended, for example, to support different operational minimums). Each approach provided by the ground system may have unique characteristics and in some sense may appear to the user to be a separate facility. Therefore, in addition to the GBAS Facility Classification, a system for classifying or designating the unique characteristics of each individual approach path is needed. For this purpose a system of Approach Facility Designations is discussed. Figure 4 illustrates the relationship between GBAS Facility Classifications and Approach Facility Designations. The classification is intended to be used for pre-flight planning and published in the aeronautical information publication (AIP).

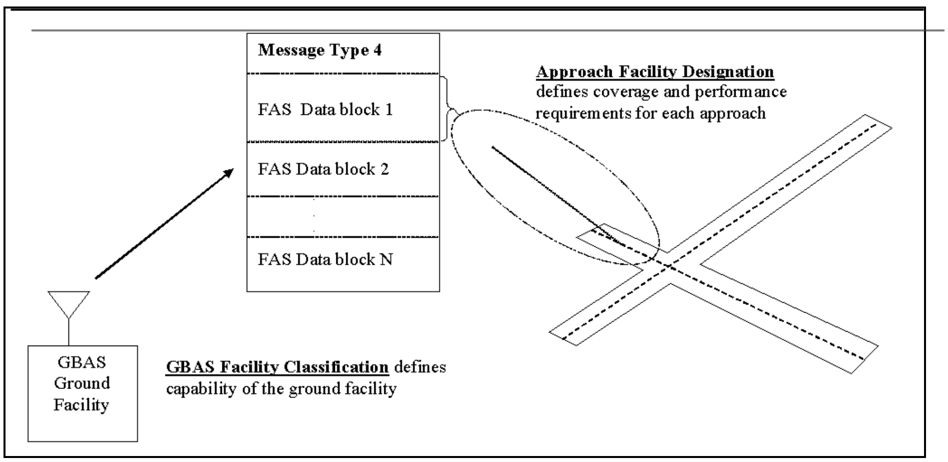

Figure 6 - GBAS Facility Classifications and Approach Facility Designations

Each approach supported by a GBAS can be characterized by an Approach Facility Designation (AFD). The AFD is composed of the following pieces of information:

GBAS Identification - Indicates the GBAS facility identifier that supports the approach (4-character GBAS ID).

Approach Identifier – Approach identifier associated with the approach in the Message Type 4 data block. It is 4 characters and must be unique for each approach within radio range of the GBAS facility.

Channel Number – Channel number associated with the approach selection. It is a 5 digit channel number between 20000 and 39999.

Approach Coverage - Indicates the minimum DH for which coverage is guaranteed of the approach. Indicates the minimum height above the ground where the signal meets the minimum requirements?

Supported Service Types – Designates the GBAS Service Types (A-D) that are supported for the approach by the ground subsystem.

Example: Approach at US Washington, DC Ronald Reagan International Airport:

"KDCA/XDCA/21279/100/CD"

KDCA	Approach is supported by the GBAS installation at DCA
XDCA	Approach ident (echoed to the pilot on approach selection) for this specific approach is "XDCA".
21279	5-digit channel number used to select the approach
100	GBAS coverage supports a decision height (DH) of 100 ft.
CD	GBAS Approach Service Types C and D are supported by ground station

5.2.4.6 GBAS Airborne Equipment Classifications

GBAS airborne equipment may or may not support multiple types of approach service that could be offered by a specific Ground Facility. The GBAS Airborne Equipment Classifications (GAEC) specifies which subsets of potentially available services types the airborne equipment can support. The GAEC includes the following elements:

The Airborne Approach Service Type (AAST) designation is a series of letters in the range from A to D indicating which GASTs are supported by the airborne equipment. For example, AAST C denotes airborne equipment that supports only GAST C. Similarly AAST ABCD indicates the airborne equipment can support GASTs A, B, C, & D.

Ranging Source Types: This field indicates what ranging sources that can be used by the airborne equipment. The proposed coding is the same as for the Ground Facility Classification.

Ground and airborne equipment designed and developed in accordance with previous versions of SARPs and RTCA DO-253A will only support GAST C. New Standards have been designed such that legacy GBAS airborne equipment will still operate correctly when a ground subsystem supports multiple types of service. Also, airborne equipment which can support multiple types of service will operate correctly when operating with a ground subsystem that supports only GAST C.

GBAS Airborne Equipment Classifications (GAEC) consist of a series of codes for the following parameters

- Ranging source: G1 – GPS, G2 – SBAS, G3 – GLONASS, G4 - Reserved for Galileo, G5+ - Reserved for future Ranging Sources)
- Airborne Approach Service : GAST A, B, C, D

The general formula is: GAEC = (Airborne Approach Service Type) / (Ranging Source Type)

For example: GAEC – CD/G1G2G4 denotes airborne equipment that supports GASTs C and D and uses GPS, Galileo, and SBAS ranging sources.

Airborne Equipment should meet the minimum requirements for

– GAEC C/G1 with optional use of DCPS (GAST C with GPS) - *CAT I operations*

– GAEC CD/G1 with optional use of DCPS (GAST C and D with GPS) – *CAT I/II/III operations*

5.2.5 Procedure Design

This section discusses the implications of GBAS operations for the four approach phases, i.e., initial, intermediate, final and missed approach.

5.2.5.1 Initial Approach

Similar to conventional navigation using ILS or other approach types, the general criteria for initial approach phases apply for GBAS. The following criteria describe details of the GBAS approaches.

In accordance with FAA orders all new approaches procedures published for use within the NAS require an initial RNAV segment. GBAS approaches will have initial RNAV segments. Within this context, ATC might use in some cases Initial Approach Fixes (IAF) different from the fixes which are currently used. This would help to arrange traffic streams in a different, more efficient way than they are arranged today. New IAF may be connected through airways or through Standard Terminal Arrival Routes (STARS), as already existing for some RNAV (GPS) Approach procedures. There should be no significant safety implications as long as the different procedures can be clearly identified.

5.2.5.2 Intermediate Approach

The intermediate approach segment has an optimum segment length of 5 NM and must be sufficient to permit the aircraft to stabilize on the final approach course. This is identical with ILS criteria. Different from ILS criteria is the fact the maximum length is governed by the requirement that it must be located wholly (including fix tolerance areas) within the service volume of GBAS. Furthermore, the distance must not exceed 20 NM from the landing threshold point (LTP/FTP).

5.2.5.3 Final Approach

The final approach segment is defined between the precision final approach fix (PFAF) and the DA/H. The PFAF is not required for the onboard equipment generation of the final approach segment. Instead of having an outer marker, a fix determining the distance from landing threshold point is defined.

The current status with regard to the glide path angle assumes that the ILS glide path angles will be applicable to GBAS CAT-I. These are: minimum/optimum 3.0°, and maximum 3.5° (based on aircraft category) for CAT-I operations. The steeper glide path angles, up to 3.5°, could be used for CAT-I approaches if this should be necessary for obstacle clearance or other reasons. For the further steps in the direction towards CAT-II and III, attention should be given to fixed wing autopilot systems, which are designed and certified for autoland functions with glide path angles between 2.9° and 3.1°. Helicopters are excluded from this limitation and are subject to separate certification criteria. The aim is to provide a cross-check point for comparison between the indicated glide path and the aircraft altimeter information.

5.2.5.4 Missed Approach

The missed approach point is a point prescribed in each instrument approach procedure at which a missed approach procedure shall be executed if the required visual reference does not exist. Within the missed approach phase no GBAS ground signal is used for track guidance. The missed approach part has to be covered by RNAV, other conventional navigation, or dead reckoning. The use of GBAS to support these operations will be considered for future development where the missed approach fixes could be transmitted with the FAS block to allow transition to Missed Approach guidance from the GLS Nav Source.

If one GBAS ground subsystem serves multiple runways, a complete GBAS signal failure may lead to simultaneous missed approaches on multiple runways. This has to be taken into account for ATC procedure planning purposes. The necessary segregation of the different missed approach procedures may increase the complexity of the procedures. Existing analyses of parallel or near-parallel approaches do not take into account the potential for simultaneous failure of both landing aids. However, procedure design and Air Traffic operational procedures can help to mitigate such additional risks.

Examples of such mitigation measures are:

- Different positions for Precision Final Approach Fix (PFAF) leading automatically to different intercept points;
- Different intercept altitudes (improved aircraft separation);
- Diverging missed approach tracks;
- Redundancy for the ground subsystem, e.g., additional reference receivers, additional transmitter antennas, backup ground subsystem.

5.2.6 Procedure Charting

Only a few changes have to be considered for GBAS approach charting in comparison to an ILS approach chart or RNAV (GPS) chart with LPV minima.

The name of the procedure has to be charted as follows: GLS plus runway, e.g.: GLS RWY 27, GLS Z RWY 35;

Instead of using an ILS frequency in MHz, a GBAS channel number with 5 digits has to be published, e.g.: Ch 22727:

The RPI for GBAS will have four alphanumeric characters. E.g. G04A or BDZK

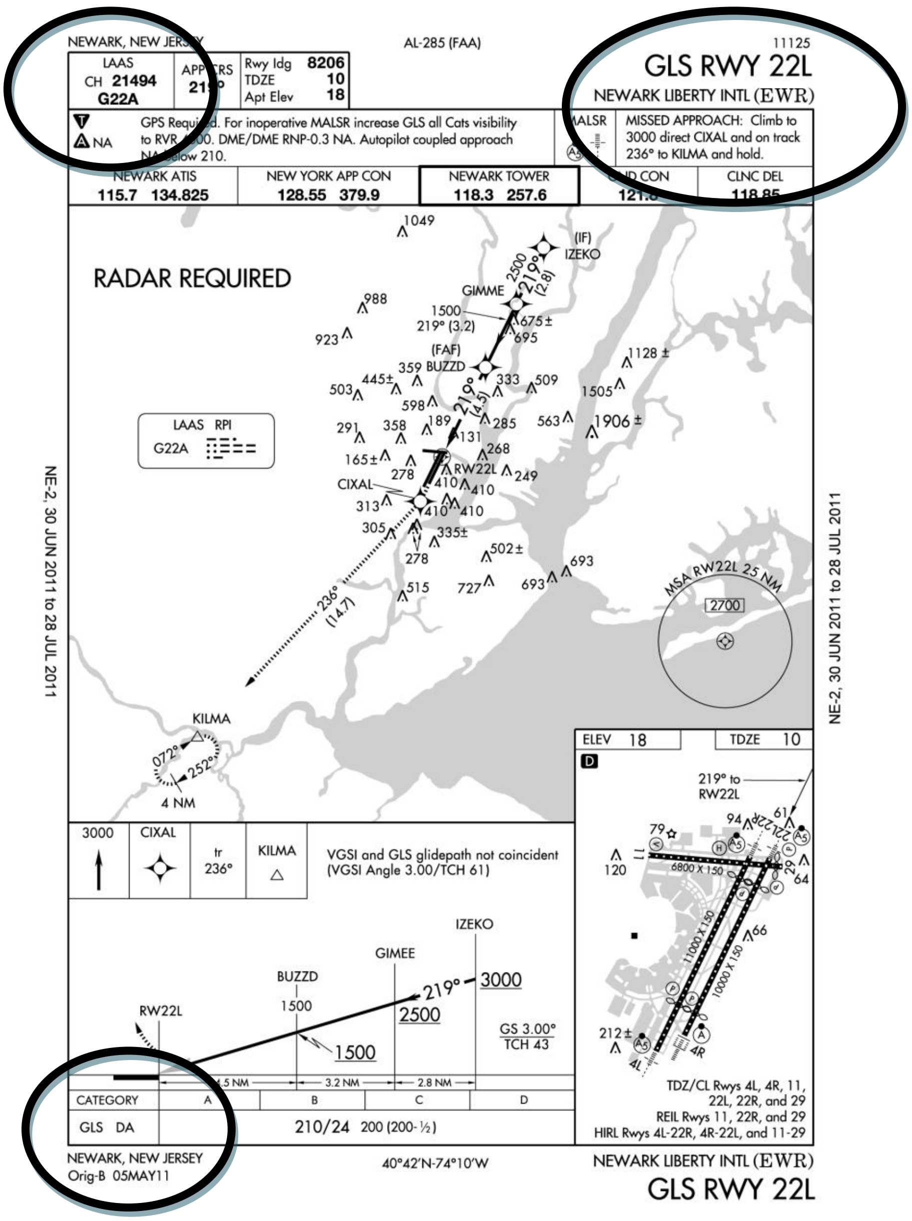

Figure 1 - Newark GLS Approach Chart

5.2.7 Flight Planning and Flight Plan

5.2.7.1 NOTAMs

Guidance for GNSS NOTAMs can be found in FAA Order JO 7930.2M and FAA Order 8260.19E and AC20-138B

Airfield-Specific GNSS NOTAMs

The following regulations are suggested for airfield-specific NOTAMs. The airfield-specific GNSS NOTAM interprets GNSS as one subject and groups all GNSS outages into one NOTAM per airfield:

- The suggested ICAO Q-code for GNSS NOTAMS is QGAAU for airfield-specific and QGWAU for area-wide NOTAMS;
- For airfield-specific NOTAMs, all GNSS outages shall be grouped into one NOTAM per airfield in order to reduce the number of overall GNSS NOTAMs; this implies that GNSS is interpreted as a single "subject" with regard to Annex 15, Section 1.2;
- The NOTAM will contain the length of the prediction window of GNSS as well as planned outages of the GBAS service. This covers the start and end time of the outages. Minimum outage time will be 15 minutes.

5.2.8 Phraseology

The term "GLS" shall be used for verbal communications. GLS is consistent with flight deck display and charts. Therefore use of "GLS" should reduce the chance during initial GBAS implementation of pilots being unable to reconcile what they hear spoken by ATC and what is on the charts and flight deck.

5.2.9 Flight Inspection

The current version of FAA Notice N 8200.116 C Change 4 "Flight Inspection/ Validation of Ground-Based Augmentation System (GBAS) Precision Approach and Flight Procedures" is applicable to GBAS.

The main items to be covered by flight inspection are:

- Database verification
  - Instrument flight procedure (initial and intermediate approach segments, final approach segment, missed approach segment, aircraft manoeuvring, cockpit workload, procedure waypoints, navigation charts, obstacles)
  - Coverage
- Minimum and maximum VDB field strength / Interference
- Ranging signal interference / VDB interference

FAA Order 8200.1C, October 2005, "United States Standard Flight Inspection Manual (USSFIM)" provides details on, when and how FAA Flight Inspection/ Validation of GBAS Precision Approach and Flight Procedures will be performed.

- *Commissioning*. The GBAS instrument approach procedures and VHF Data Broadcast (VDB) coverage must be evaluated during initial flight inspection/ validation. If provided, each TAP procedure must be evaluated during initial inspection. If airport surface operations are supported, the applicable electronic map and VDB signal coverage must be evaluated during initial inspections
- *Periodic.* LGF is to be configured in normal mode. VDB coverage along the lower orbit will be evaluated based on loss of signal and data continuity alerts. The altitude established for the lower orbit during commissioning must be used. The LGF broadcast FAS data block cyclic redundancy check (CRC) will be checked for each Standard Instrument Approach Procedure (SIAP) and TAP. Approach obstacle verification scheduling must be completed in accordance with FAA Order 8200.1, Chapter 4. VDB signal coverage on the airport surface may be required depending on the level of service provided, and the airport map data CRC will be checked to ensure there has been no change or corruption
- *Special.* A special flight inspection evaluation is required subsequent to select maintenance actions, for a change in VDB antenna, antenna type or antenna phase center location, whenever physical changes occur at the site having the potential to effect GPS signal reception and VDB coverage, such as new obstructions or construction or in response to multiple user complaints. Flight evaluation/validation is required when an existing approach or TAP procedure is modified or when a new approach or TAP procedure is added to an operational facility. Some of the changes may require reassessing the safety (integrity) impacts resulting from these changes before the changes are adapted.

5.2.10 Training

This section deals with aspects related to GBAS specific training for pilots, controllers and air navigation service providers.

5.2.10.1 Pilots

GBAS CAT-I will be initially an "ILS look-alike" approach, including the pre-dispatch facility NOTAM check. Training can be kept to a minimum. Operators may provide GBAS training in the form of a bulletin and may choose to incorporate events into normally scheduled training or simulator sessions.

If the future design of on-board equipment (e.g. GBAS standalone equipment, potential AFCS modifications, etc.) raises a need for comprehensive cockpit refurbishment, additional steps of training may need to be considered before using GBAS.

5.2.10.2 ATC / Controllers

According to the current processes of controller training, there is no need to train controllers on the exact details of procedure design of GBAS CAT-I approach criteria. As a minimum requirement, controllers should have a briefing bulletin explaining:

- the GBAS system,
- GPS NOTAMS (content, meaning, etc.),
- GPS/GBAS specific phraseology,
- Mixed mode operations,
- Determination of landing aid to be used for aircraft as a function of aircraft equipage,
- GBAS ground subsystem requirements,
- On-board requirements.

Especially with regard to on-board requirements, it is important that the controller has some insight into the aircraft limitations and restrictions. Furthermore, the controller has to be aware how to react to system failures on the ground side (refer to paragraph 7.1).

Whenever the complexity grows, e.g. multiple runway usage or mixed mode of ILS, RNAV(GPS) and GBAS, extra controller training will be necessary. This training will take into account the local procedures including handover procedures between approach and tower.

5.2.10.3 Air Navigation Service Providers

Instrument approach procedures will be based on TERPS. All aspects of procedure design e.g. construction of procedure areas, obstacle assessment areas, associated themes should be covered.

The responsible air navigation service provider has to provide the necessary national framework, (i.e. rules and regulations) and evaluate their implementation.

6 OPERATIONS

6.1.1 Operational changes on the flight deck and within ATC facilities

6.1.1.1 Pilots

Operational changes to the flight deck have already been implemented through the introduction of GBAS CAT I standards. New Airbus and Boeing aircraft are either GLS equipped or have GLS equipage as an option. Cockpit annunciation and integration has been completed.

With the implementation of GBAS as a new precision approach, operators amend their Flight Operations Manual, (FOM) and Flight Standards Manual (FSM) and Operations Specifications (or equivalent) according to the change in cockpit procedures and the installation of a GBAS system in the aircraft.

GLS procedures and techniques are in principle identical to an ILS approach. Operator training can be accomplished through aircrew training bulletin and is already in place with certain national and international airlines.

The pilot's perspective for a GBAS ILS look-alike approach is equivalent to the ILS approach except for the following points:

- Channel and approach name is different
- GLS replaces ILS on the EFIS
- Phraseology differs ILS/GLS

As long as the ILS 'look-alike' concept is considered, changes to pilots' procedures will be minimal and limited to minor changes (phraseology, approach plate and briefing, and those identified below):

- Flight Planning:

When planning a GBAS CAT I approach the pilot has to check the availability of the procedures by reading the corresponding GNSS NOTAMs in order to gain information on both destination and alternate airports, on failure of GBAS ground subsystems, on known GPS outages due to maintenance, and so on. A GBAS prediction tool will support the flight planning phase.

- GBAS approach availability check in navigation database:

When GBAS approach is to be selected from an FMS interface the flight crew checks prior to each flight whether all planned approaches at the destination airport and/or the alternate airport is properly stored in the aircraft database.

- Meteorological conditions:

No change to ILS practice: The ability for the flight crew to perform a precision approach of a certain category depends on the weather conditions. These are expressed by means of an RVR (Runway Visual Range) value.

- Aircraft system status:

Like with ILS, before starting the approach the pilot must check his aircraft system status and verify which precision approach category (CAT I, II, or III) the aircraft system status allows.

- GBAS Approach Tuning:

All standard procedures applied in conventional navigation, such as frequency switching and signal identification, are still required and can be maintained. Interpretation of guidance will be equal to today's ILS approach, apart from the fact that GBAS-specific information (the Reference Path ID or RPI) has to be indicated. The display of the RPI indicates that the VDB transmission was successful and complete and that messages are being processed for the selected approach. The RPI of the GBAS approach has to be cross-checked against the data from the approach chart before starting the final descent. Operationally, there is no difference with today's situation, where the ILS ident should be cross-checked. When GBAS is manually tuned, the risk of a wrong channel selection by the cockpit crew will be minimized by:

    - Firstly, RPI (Reference Path ID) displayed on the PFD of the cockpit is cross-checked against the approach charts by the flight crew
    - Secondly, all channel numbers transmitted by a GBAS ground subsystem will differ in at least three of the five digits.

- Approach interception:
  For approach interception and the switchover to APP mode from the initial intercept the principles and procedures for ILS apply, for GBAS navigation the same process is applicable (operational requirement).

6.1.1.2 ATC / Controllers

The responsibilities of the controllers for separation between aircraft remain unchanged. The responsibility of the approach control services is to provide radar vectoring in order to intercept the final approach course if the GBAS final cannot be intercepted by using (RNAV or other) standard procedures.

For ATC it is important to have the ability to monitor the GBAS ground subsystem functionality (as with ILS today). This includes a status-check of GBAS ground subsystem and performance of the GBAS signal, which indicates to the responsible controller whether approach clearance can be given or not.

There is no common standard for the GBAS ATC User Interface. In the US NAS ATC will be able to monitor the GBAS status in an Air Traffic Status Unit (ATSU). The approach configuration is generated through maintenance interface and loaded to the GBAS station and the maintenance interface provides also for means to enable or disable all approach configurations simultaneously. The configuration of approaches and their availability via the maintenance interface should only be possible on a non-operating GBAS station (i.e. in maintenance mode). For the presently installed CAT GBAS no enabling/disabling of approaches is possible through ATC interface.

However it also possible to integrate GBAS information into an ATC interface which not only provides GBAS related information, but also merged information acquired from different sensors to the ATC. Such sensors are providing information on the runway lighting status, weather information and GBAS ground station status information. The ICMS (integrated control and monitor system) used in the NAS at different locations is such a system.

Controllers should train for the possibility of GBAS component failure. In case of a GPS or GBAS signal outage an aircraft on the final approach may continue to land under visual conditions or execute a missed approach procedure. If more than one runway is using GBAS approach procedures, all aircraft on final approach which are unable to revert to a visual or alternate approach must execute a missed approach. Aircraft on a RNAV based initial or intermediate approach phase of a GBAS standard approach procedure may revert to GPS or conventional procedure if the GBAS ground subsystem fails and time permits. In case of total GPS failure, no further satellite based navigation is available. Therefore, if an aircraft loses complete GPS guidance, ATC must be informed and the aircraft has to revert to other navigation. If no alternate procedure is published and if meteorological conditions will not support visual approaches for the destination airport the pilot will have to divert to an alternate aerodrome. This may cause an increase in ATC workload.

Mixed mode operations may be accomplished when GBAS CAT-I, RNAV (GPS), and ILS approaches are operated simultaneously on the same runway. This mixed mode operation requires the coordination of the approach type from the approach controller to the tower controller. The knowledge of the approach type in use is essential for the tower controller in case of approach system malfunctions and/or missed approaches. This handover procedure must be addressed in the local approach/tower controller procedures. During mixed mode operations any advantages obtained due to GBAS, such as critical area reduction, must be suspended

6.1.1.3 GBAS Impact on air traffic management procedures and concepts

The introduction of new technology approach and landing aids such as GBAS will be done, in many cases, in runways already equipped with ILS. ATC procedures for managing mixed ILS/GBAS equipage operations have to be developed. Some airport installing GBAS might have a medium demand (no capacity constraints) such that there is no need to benefit from the reduced critical and sensitive area. It is assumed that both systems use the same threshold and glideslope so that each approach profile looks the same to ATC. ATC will need to know which aircraft will perform a GBAS and which aircraft will perform an ILS approach. This can be solved through R/F communication or ATC HMI implementation based on the information available from the flight plan.

When installing GBAS with the objective to increase capacity, optimized low visibility operations using GBAS can be implemented. This can be achieved through the use of the landing clearance line and the provision of the late landing clearance can be developed. However this operation is a bit more challenging when both ILS and GBAS landing systems continue to provide for CAT III operations, ATC will need to know if the aircraft is equipped with ILS or GBAS to properly manage the aircraft.

GBAS eliminates ILS critical areas. This reduces arrival and taxi delays. GBAS in combination with RNAV and RNP procedures will allow for predictable flight paths in the terminal area which potentially reduce pilot controller communications workload and the variability in the time and distance flown in the terminal area and lead to more flexible routing.

GBAS may improve reduced separation in arrival operations, because it can provide multiple, individually selectable approaches to the same runway which may have different glide paths, as well as displaced thresholds. A combination of offset thresholds and different glide-path angles can be used to ensure smaller aircraft will not be affected by the wake-turbulence generated by larger aircraft. This capability supports reduction in separation by mitigating wake turbulence.

When no optimization is required, to change from ILS landing system to managing mixed ILS and GBAS landings is considered not very complicated for air traffic control as the spacing applied and runway holding points are the same. There is a need for ATC to know which landing aid the aircraft is using for GBAS operations when both systems are available so that any degradation of service is informed immediately to flight crew. This concept is beneficial for airport where increasing capacity is not the main objective. Instead the Airport has identified other benefits from the use of GBAS such as system resilience to multipath for restricting environments or snow; flexibility of movement close to runway as the station can be located further away; the use of one system for multiple runways etc.

When optimization is desired during the use of both ILS and GBAS landing systems ATC has more complicated tasks. In this case ATC can reduce the final approach spacing before a GBAS arriving aircraft. Also ATC will need to manage two different runway vacation positions for ILS and GBAS. And ATC will use two different distances for providing the latest landing clearance to arriving aircraft, 1NM for GBAS arrival and 2NM for ILS arrival.

6.1.2 Supporting Infrastructure

GBAS is dependent on the continued availability of DoD's GPS.

GBAS is a stand-alone approach and landing navigation system.

GBAS is a single system and compared to ILS does **not** require separate systems for Glideslope, Localizer, Outer-Middle-Inner marker for the precision approach operations.

GBAS will need to interface with National Airspace systems for maintenance and monitor purposes, e.g. the NOTAM system and the Remote Maintenance System (RMS), not required if GBAS is implemented as a non-Federal system.

7 BENEFITS TO BE REALIZED

User Benefit	FAA Benefit	Benefit Description
	Access and Equity	GBAS-equipped aircraft can increase overall airport access by offloading GLS capable aircraft to a runway where the ILS is not working, thereby allowing the ILS aircraft to use any remaining operational ILS runways and by reducing the overall traffic count lining up to use those same operational ILS runways.
	Capacity	GBAS provides an alternative to the ILS for Category II/III approach. Where appropriate, GBAS can be used to eliminate ILS critical areas, which increases capacity at some runways and airport within the NAS. GBAS also provides a lower decision altitude than other SATNAV systems, improving access in low-visibility conditions.
Efficiency	Efficiency	Aircraft operators will benefit from reduced fuel expenses due to more direct terminal area routing and improved access to airports during extremely low visibility operations. GBAS, in combination with RNAV and RNP procedures, will allow for predictable flight paths in the terminal area which could potentially reduce pilot controller communications workload and the variability in the time and distance flown in the terminal area and lead to more flexible routing.
	Flexibility	GBAS does not have ILS critical areas. This reduces arrival and taxi delays. GBAS can permit take off operations in low visibility, which reduces departure delays for properly equipped aircraft. As an alternate/additional GNSS precision landing system, GBAS will reduce the number of flight disruptions in a terminal area, and provides fewer inclement weather delays. GBAS can be installed at airports that currently do not have precision approaches due to ILS siting constraints, improving capacity at that specific airport.

User Benefit	FAA Benefit	Benefit Description
		GBAS capability for displaced threshold and variable glide path provides flexibility in the terminal environment and potential for improved closely parallel operations/wake turbulence avoidance/noise reduction.
Safety	Safety	GBAS can also be installed at airports that currently do not have precision approaches due to ILS siting constraints, improving safety at that specific airport. GBAS will reduce the number of flight disruptions in a terminal area as an alternate/additional GNSS precision landing system.
	Cost Avoidance	The FAA will incur lower annual maintenance costs for GBAS, because a single GBAS ground installation will service all runway ends at an airport compared to the current technology that requires multiple ILS systems at a given airport. With GBAS, the FAA will obtain the benefits of reduced maintenance and life cycle costs and avoid re-capitalization of aging ground based navigation systems.
	Environmental	Contributes to the protection of the environment by considering noise, emissions, and other environmental issues in the implementation and operation of the aviation system. GBAS provides the capability of multiple approached per runway end with variable glide path and displaced thresholds for noise abatement

8 OPERATIONAL SCENARIOS

8.1 Nominal operational scenario

The table below presents the operating procedures and related GBAS specifics. This nominal scenario is based on the present GBAS GAST-D design requirements and does not include potential additional capabilities the technology could provide (terminal area path, DCPS, guided missed approach/departure, variable glidepath, displaced threshhold procedures)

The nominal scenario has been divided into the following steps to address the main phases of flight:

- Pre-flight
- Start, taxi, take off
- Enroute
- Prior to commencing the approach – upstream IAF
- Initial and intermediate approach – IAF to FAF
- Final approach
- Missed approach

Phase of flight	Operator	Operations
Pre-flight		
Flight plan	Aircrew	The flight plan should contain information about the GBAS capabilities of the aircraft. The provision of GBAS capability is needed by ATC in order to know which navigation aid the aircraft is capable of using for approach and landing. This designation would indicate the GBAS capability onboard, and not which type of GBAS approaches the aircraft is capable of. This concept is compatible with current ILS operations; the pilot is supposed to request a GBAS approach only if; the aircraft is capable of and the pilot is qualified for the procedure and the adequate flight ops procedures are in place.
GBAS NOTAM	Aircrew	The GBAS NOTAM should notify of the service unavailability of the GBAS ground station to support the CATII/III operation. In the US NAS It is required to use prediction models to predict GLS procedure unavailability, predictable service outages must be provided to pilots and dispatchers If unavailable for approach, a NOTAM is issued NOTAM format is in principle similar to ILS:
Weather forecast	Aircrew	No specifics related to GBAS

Space weather forecast	Aircrew	No specifics related to GBAS
Operating minima for destination and alternate airport	Aircrew	No change to existing precision approach procedures (ILS), airline operations depending on destination, alternate and aircraft equipage
Start, Taxi, Take-off		
Navigation database	Aircrew	No specifics related to GBAS Nav DB is checked during recycling of its content every 28 days and there is no GBAS specificity associated to that. Besides, a GBAS approach can be selected in back-up mode since Approach data (i.e. Final Approach Segment=FAS) are received from the GBAS ground station.
Airborne systems check	Aircrew	The airborne systems needed are at least GLS Receiver (e.g. MMR), Automatic Pilot, Breaking System, Radio-Altimeter, ADIRU. The check is done automatically and displayed on the Flight Mode Annunciator. Before each flight, for example, there is a check of the autoland capability through the LAND TEST only pertaining automatic landing capability not related to signal-in-space done for ILS and GLS.
Departure	Aircrew	The present GBAS GAST D design does not provide departure guidance. Departure can to be flown with conventional procedures or with RNAV/RNP where applicable.
Enroute		
	Aircrew	No specifics related to GBAS
Top of descend		
ATIS approach data for the destination airport	ATC Aircrew	No specifics related to GBAS Both GLS approach information and GBAS GS information should be provided by the ATIS. The GBAS station status might be provided through broadcasting the navigation aid identifier, the approach identifier, channel number, runway threshold and GBAS station status. In the airports where there is no ATIS, the GLS approach availability would be confirmed in controller-pilot RF communication.

Approach preparation	Aircrew	Selection of an APPR, STAR, TRANS and APPR VIA. Check the information via the Navigation Display for trajectory and altitude / speed constraint verification. Enter the wind and performance data for descent and approach. Check the tuning of the appropriate navaid with information provided on PFD or ND. Checks through MFD NAVAIDS page that the precision approach is tuned. Note that at this distance, the precision approach mean is unlikely to be received. GBAS Specific The output of deviations is limited to within Dmax in GBAS standards. Pilots have expressed the desire to tune the approach and see deviations outside the precision approach region or outside Dmax for similarity to ILS and for confirmation of station operation.
GLS approach clearance	ATC Aircrew	In the US NAS the GLS (term consistent with avionics annunciators and charts) is used when referring to approach. The ATC would issue a GLS approach clearance. No distinction on the precision approach category is made. Phraseology is similar to ILS clearance except replacing it with GLS No international standards for ATC interface are available (this is a national responsibility). The GBAS ATC interface should display the GBAS approach service status. ATC should be informed of the aircraft equipment (i.e. GBAS and/or ILS capable). This is all the information needed by the ATC to clear the GLS approach.
RNAV procedure or radar vector	Aircrew ATC	GLS approach can be connected to conventional or RNAV or RNP segments. GLS approach can also be open procedure requiring radar vector but at least an IF waypoint needs to exist.
Approach selection and briefing	Aircrew	GLS approach can be selected either by the name of the procedure or by the channel number. It should be completed during the flight planning, or the preparation of the approach and prior to the RNAV sequencing. This is done through the flight plan and automatically tuned while still enroute. Otherwise, the approach must be selected sufficiently in advance to enable the on-board receiver to receive all the messages from the ground station and ensure a stabilized approach no later than at 1000 ft. Ident displayed on the PFD is used to check the correct approach is selected. Approach briefing should be carried out at top of descend well in advance ▪ Aircraft capability ▪ Airport facilities ▪ Crew qualification ▪ Weather minima

		▪ Task sharing ▪ Call-outs ▪ Go-around strategy
GLS approach availability:	Aircrew	When the aircraft reaches the arrival airport terminal area, the crew check that the FMS approach phase has been activated. If not, the crew needs to force the activation of the approach phase. Check that the proper navaids are tuned so that the GLS associated to the runway forecasted for landing is correctly tuned and correctly received. GBAS ID and RPI are decoded compared to the information on the chart, using Displays. Once the approach is selected, the pilot will automatically get deviations within GBAS ground station coverage. LOC and G/S scales and deviations are displayed on PFD.
Initial and intermediate approach – IAF to FAF		
Autopilot use	Aircrew	Autopilot is required in CAT III conditions. There are no specifics with GBAS.
RNAV to GLS transition	Aircrew	Transition from RNAV/RNP to GLS is similar to ILS but procedures depend on aircraft integration If ATC provides radar vectors, the crew will use DIR TO RADIAL IN. This ensures: ▪ A proper F-PLN sequencing ▪ A comprehensive ND display ▪ Assistance for lateral interception.
Approach arming	Aircrew	Once cleared for the approach by the ATC, the crew arms the approach, monitors the capture of the LOC and of the G/S to announce it when displayed on the FMA, and monitors the FMA display for the aircraft capability. GBAS specific The output of deviations is limited to within Dmax
Final Approach		
Final approach intercept path	Aircrew	No GBAS specifics There are no differences between ILS and GBAS, however, lateral capture limitations may be applicable because of different OEM integration
Approach monitor	Aircrew	A monitoring of AUTOLAND conditions is performed in order to warn the crew on failure conditions that requires performing an immediate go around. No GBAS specifics, however, recommended that distance check at around 3 to 5NMs should be maintained as it represents the gate at which everything needs to be checked before landing (aircraft configuration, cabin crew warning etc…) similar to ILS

		where an OM evolved to a distance check point at an equivalent distance.
Decision for landing	Aircrew	No GBAS specifics Use of radio altimeter to determine the decision height as done with ILS in Cat II/III conditions. Decision to land or go-around must be made at DA/DH at the latest. Reaching the DA/DH, at MINIMUM call out: If suitable visual reference can be maintained and the aircraft is properly established, continue and land. If not, go-around.
Missed approach		
Missed approach	Aircrew	The missed approach can be initiated at any point of the final approach segment. There are no specific mechanisms in GLS conducting to a missed approach which may be performed with a RNAV system. Missed approach guidance is a regular FMS guidance function and does not require GLS lateral or vertical deviation data; the AFCS is not coupled to MMR, deviation outputs during the missed approach.
Transfer from approach to tower control	ATC	In a GBAS only environment no specifics. In a mixed landing mode coordination between approach ATC and tower ATC is required. A local MoA should cover the minimum aircraft spacing for mixed GBAS/ILS modes. Local ATC procedures and letters of agreement should be established.
Landing clearance	ATC	No GBAS specifics An absolute descent height restriction before receiving a landing clearance has to be set. If the crew has not received a landing clearance at this point they must go around. This is similar to ILS. Lighting and airport infrastructure has to be compliant with ICAO annex 14 concerning CAT II/III operations

Table 4 Nominal operational scenario

9 SUMMARY OF IMPACTS

The FAA will incur lower annual maintenance costs for GBAS because a single GBAS ground installation will serve all runway ends at an airport compared to the current technology that requires multiple ILS systems at a given airport. With GBAS the FAA will obtain the benefits of reduced maintenance and life cycle costs, and avoid re-capitalization of aging ground based navigation systems (ILS less than VOR less than DME and NDB).

GBAS eliminates ILS critical areas. This reduces arrival and taxi delays specific to capacity. GBAS will maintain VMC/MVMC airport operations in IMC. GBAS in combination with RNAV and RNP procedures will allow for predictable flight paths in the terminal area which could potentially reduce pilot controller communications workload and the variability in the time and distance flown in the terminal area and lead to more flexible routing for improved efficiency.

A single GBAS ground facility can provide service to all runways ends at an airport; compare this GBAS feature to the need to purchase and install a separate ILS for each runway end at an airport. The number of ILS systems and their design complexity makes the ongoing costs of supporting these systems higher than those for GBAS. A GBAS cost analysis was performed in 2006 with the purpose of establishing the potential long-term cost benefit of GBAS. The study demonstrates that net life-cycle cost savings begin to accrue if two ILSs are divested for every one GBAS station installed at each of the 118 identified airports.

GBAS will reduce the number of flight disruptions in a terminal area by improving ceiling and visibility minima. Lower minima can result in fewer flight cancellations, fewer diversions to alternate airports, and fewer inclement weather delays per the Capacity KPA. GBAS can provide fewer arrival and taxi delays than ILS. GBAS can permit takeoff operations in low visibility, which reduces departure delays for properly equipped aircraft. GBAS in combination with RNAV and RNP procedures will allow for predictable and configurable flight paths in the terminal area which will lead to more flexible routing in the terminal area , reduced fuel consumption, and reduced flight times. GBAS may also reduce a pilot’s workload by requiring fewer communications with ATC. A reduction in flight time equates to savings for both airlines and passengers. GBAS will reduce the number of airline disruptions (delays, cancellations, and diversions).

List of Abbreviations

ACSF	ATC Control and Status Function
AFCS	Automatic Flight Control System
AIP	Aeronautical Information Publication
AIS	Aeronautical Information Service
AMDT	Amendment
ANSP	Air Navigation Service Provider
APP	Approach
ARINC	Aeronautical Radio Inc.
ATC	Air Traffic Control
ATM	Air Traffic Management
ATS	Air Traffic Service
CAA	Civil Aviation Authority
CAT-I, -II, -III	Category I, II, III Precision Approach
CBT	Computer Based Training
CDI	Course Deviation Indicator
CRM	Collision Risk Model
COM	Communication(s)
DA/H	Decision Altitude/Height
DEST	Aerodrome of Destination
Dmax	Maximum Use Distance
DME	Distance Measuring Equipment
DDM	Difference in Depth of Modulation
DR	Dead Reckoning
FAA	Federal Aviation Administration
FAF	Final Approach Fix
FAP	Final Approach Point
FAS	Final Approach Segment
FDE	Fault Detection and Exclusion
FDPS	Flight Data Processing System
FHA	Functional Hazard Assessment
FIRs	Flight Information Region
FMS	Flight Management System

FPAP	Flight Path Alignment point
FPL	Filed Flight Plan (also: AFTN Filed Flight Plan Message)
FSD	Full Scale Deflection
FTP	Fictitious Threshold Point
GA	General Aviation
GARP	GBAS Azimuth Reference Point
GBAS	Ground-Based Augmentation System
GCID	GBAS Continuity Integrity Designator
GDPS	GNSS Differential Positioning System
GLS	GBAS Landing System
GNSS	Global Navigation Satellite System
GNSSP	GNSS Panel
GPA	Glidepath Angle
GPS	Global Positioning System
GP INOP	Glide Path – Inoperational
GS	Ground System
G/S	Glide Slope
HAT	Height Above Touchdown
HDG	Heading
IAF	Initial Approach Fix
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
IAF	Initial Approach Fixes
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
INS/IRS	Inertial Navigation System / Inertial Reference System
LAAS	Local Area Augmentation System
LAL	Lateral Alert Limit
LTP	Landing Threshold Point
LOC	Localizer
LNAV	Lateral Navigation
LRU	Line Replaceable Unit
MA	Missed Approach

MAP	Missed Approach Point / Aeronautical Maps and Charts
MASPS	Minimum Aviation System Performance Specification
MM	Middle Marker
MMR	Multi-Mode Receiver, Airborne
MOC	Minimum Obstacle Clearance
MOPS	Minimum Operational Performance Standard
NOTAM	Notice to Airmen
MT1	Message Type 1
MT4	Message Type 4
NAV	Navigation
NM	Nautical Mile
NPA	Non-Precision Approach
OAS	Obstacle Assessment Surface
OCA	Obstacle Clearance Altitude
OCH	Obstacle Clearance Height
OCP	Obstacle Clearance Panel
OM	Outer Marker
PANS	Procedures for Air Navigation Services
PANS-OPS	PANS – Aircraft Operations
PFAF	Precision Final Approach Fix
PFD	Primary Flight Display
RAIM	Receiver Autonomous Integrity Monitoring
RF	Radio Frequency
RFI	Radio Frequency Interference
RNAV	Area Navigation
RPI	Reference Path Identifier
RSDS	Reference Station Data Selector
RTCA	Radio Technical Commission on Aeronautics / RTCA, Inc.
RVSM	Reduced Vertical Separation Minimum
SAM	Safety Assessment Methodology
SARPS	Standards and Recommended Practices
SBAS	Space-Based Augmentation Systems
SMS	Safety Management System

SID	Standard Instrument Departure (Route)
SIS	Signal In Space
SSU	System Monitoring and Control
TCH	Threshold Crossing Height
TRL	Transition Level
TSO	Technical Standard Order
THR	Threshold
TMA	Terminal Area / Terminal Maneuvering Area
VDB	VHF Data Broadcast
VHF	Very High Frequency
VMC	Visual Meteorological Conditions
VNAV	Vertical Navigation
VOR	VHF Omnidirectional Radio (108-118 MHz)
WGS84	World Geodetic System 1984

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